WRRC Report No. 4
March 1984

A Survey of Water Quality in USDA Agricultural Ponds Within Blue Earth County, South Central Minnesota

Water Resources Research Center
University of Minnesota Graduate School

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Limnological Contribution Number 27
Mankato State University

Publication of this thesis was partially supported by the University of Minnesota, Water Resources Research Center, from funds provided by U.S. Department of the Interior, Washington, D.C. Cover Photography Courtesy of the Freshwater Society, Navarre, Minnesota

A thesis submitted in partial
fulfillment of the requirements for the
degree of Master of Arts at
Mankato State University

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A SURVEY OF WATER QUALITY IN USDA AGRICULTURAL PONDS WITHIN BLUE EARTH COUNTY, SOUTH CENTRAL MINNESOTA

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Mankato State University, 1983

The effects of construction method (excavation, dynamite), geomorphic (glacial till, lacustrine) and hydrologic (marsh, terrestrial) setting, and usage on water quality in eleven USDA agricultrural ponds within Blue Earth County, Minnesota were examined during the ice-free season of 1982. Dissolved oxygen, total Kjeldahl nitrogen, nitrate nitrogen, total orthophosphate phosphorus, turbidity, condictuvity, and light penetration levels within the water column were monitored. Total Kjeldahl nitrogen, total phosphorus, and organic matter percentages within the sediment were also determined. A survey of organisms including aquatic macrophytes, fish, zooplankton, molluscs, and benthos was also conducted for descriptive purposes.

Statistical analysis revealed significant differences in means and correlation direction between the categories comprising the above variables. However, it was hypothesized that these variables were not the principal factors determining the disparities in water quality. Instead, extensive blooms of Lemna upon the water surface were more influential, since this condition within the ponds resulted in anoxia. Mean total Kjeldahl nitrogen and total orthophosphate concentrations within the water column were significantly greater among Lemna covered ponds as a result of this condition. It is proposed that ponds be constructed and managed such that eutrophying nutrients remain trapped within the pond sediments so that potential receiving water bodies are not negatively affected.

Key words: agricultural pond; conservation; eutrophication; water quality

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ACKNOWLEDGEMENTS

Much recognition and gratitude are extended to all persons who offered assistance for which I am indebted: foremost to Dr. Henry Quade of Mankato State University for his generous support and guidance throughout this project; to Dr. Duane Braaten, also of Mankato State University, for which his contribution to the statistical phase was greatly appreciated; to the Blue Earth County Soil Conservation Service, toward their resourcefulness at the commencement of this study; to those who aided in various facets involving field work, namely Kevin King and Paul Fasching. Their camaraderie was most appreciated.

Finally, I am grateful to all the landowners for their cooperation and cordiality. They included the following: Wallace Frank, Tom Hensel, Ambrose Kopp, Harlan Marble, Wendell Wessman, and Alonzo Wingen.

This study was funded, in part, by Mankato State University Faculty Research Grant to Dr. Henry Quade.

INTRODUCTION

More than 2.1 million ponds had been built in the United States by 1980 on privately owned land (SCS, 1982). Forty-nine government subsidized ponds have been built since 1967 in Blue Earth County alone, of which forty-five percent were constructed in the years 1980 and 1981. Government ponds have served a variety of purposes and needs, including water for livestock, irrigation, fish production, wildlife habitat, recreation, and for lanscape improvement to name a few. Agricultural counties have been, and continue to be, heavily committed to the construction of agricultural ponds as a conservation practice. Construction has been federally funded since 1959; recently at seventy-five percent cost not to exceed $3,500 per year.

The national interest in eutrophication has resulted in extensive studies on nitrogen and phosphorus; however, little research has been done with regard to the role of these two elements within agricultural ponds. If method of construction, usage, or setting have an effect on water quality, this information would be of value in the design stage for county, state, and federal planners.

This thesis addresses the question of water quality differences in relation to three sets of variables: method of construction, hydrologic setting, and geomorphic setting as found in a single county in South Central Minnesota. The usage of the pond was also an initial variable; however, it was not statistically treated due to the lack of consistency of stated use to actual use. Its purpose is not only to attempt to answer questions concerning the quality of water in agricultural ponds, but further to formulate new hypotheses for the betterment of water quality in ponds. The information gained from this study is therefore intended to be utilized as input for future design criteria for, and management of, agricultural ponds. It should also serve as base data for future research.

General Survey of Ponds in Blue Earth County

A survey of ponds in Blue Earth County was made utilizing the records of the County Soil Conservation Service. The survey did not take into account ponds which were built without assistance from the SCS because of lack of records.

Based on the information at the SCS, forty-nine ponds were constructed between the years 1967 and 1981 with the greatest number of ponds built in 1980 (Table 1). Ten ponds were constructed in 1969 although eight of these belonged to a single land owner. Thirty-eight of the forty-nine ponds constructed were intended for wildlife, seven for livestock, two for fish, and two for both livestock and wildlife.

Four methods were utilized in the construction of the ponds: excavation, dynamite, construction of an embankment, or a combination of both dynamite and an embankment. Construction by the use

Table 1. Breakdown of intended purpose of ponds and construction method by year.

		Year															number of each
		1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	
INTENDED PURPOSE	Wildlife	0	2	10	0	0	0	0	1	0	4	1	1	0	14	5	38
	Livestock	1	0	0	0	0	0	0	1	1	1	0	0	0	2	1	7
	Fish	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	2
	Wildlife-livestock	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	2
CONSTRUCTION METHOD	Excavation	1	2	1	0	1	1	0	2	2	5	1	1	0	5	1	23
	Dynamite	0	0	8	0	0	0	0	0	0	0	0	0	0	11	5	24
	Embankment	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
	Embankment-dynamite	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
TOTAL		1	2	10	0	1	1	0	2	2	6	1	1	0	16	6	49

of dynamite and by excavation have been by far the most common methods with each being equal in number, and both together totaling forty-seven of the forty-nine ponds (Table 1). All ponds built by using dynamite were intended to serve as wildlife ponds; and of the twenty-four ponds excavated, thirteen were intended for wildlife, seven for livestock, two for fish, and one for the combination of both livestock and wildlife (Table 2). One should note that all livestock and fish ponds were excavated; the reason being that this method ensures that both the proper dimensions and the desired depth will be attained. Livestock ponds require a gradual slope at the entrance of the pond and a fish pond must be deep enough in order to sustain a viable fish population. The one exception to this is that the wildlife-livestock combination pond was built by constructing an embankment. The only dynamite-embankment built pond was a very large pond (212,600 ft^2) which was constructed for wildlife.

Table 2. Numbers of ponds with respect to purpose by each construction method.

Construction Method	Purpose: Wildlife	Livestock	Fish	Wildlife-livestock
Excavation	13	7	2	1
Dynamite	24	0	0	0
Embankment	0	0	0	1
Embankment-dynamite	1	0	0	0

From 1969 to 1981, ponds generally decreased in construction size with respect to surface area. Ponds constructed by using dynamite were much smaller in surface area as compared to those which were excavated (about one-fourth the size). In addition, ponds built in 1980 and 1981 were primarily dynamited and few were excavated. Therefore, since the use of dynamite in the construction of ponds has increased in recent years, this may be responsible for the accompanying decrease in surface area of the ponds in general. Also, with respect to average size, ponds built for fish were considerably larger than either wildlife or livestock ponds.

Description of the Study Area

Location

Eleven ponds were selected for the study based upon construction, setting, and usage, and were found in the eastern half of Blue Earth County in South Central Minneaota (Figure 1). The ninety-fourth meridian of west longitude crosses the forty-fourth parallel of north latitude near the center of the county. Figure 2 shows the location of each pond in the county by code.

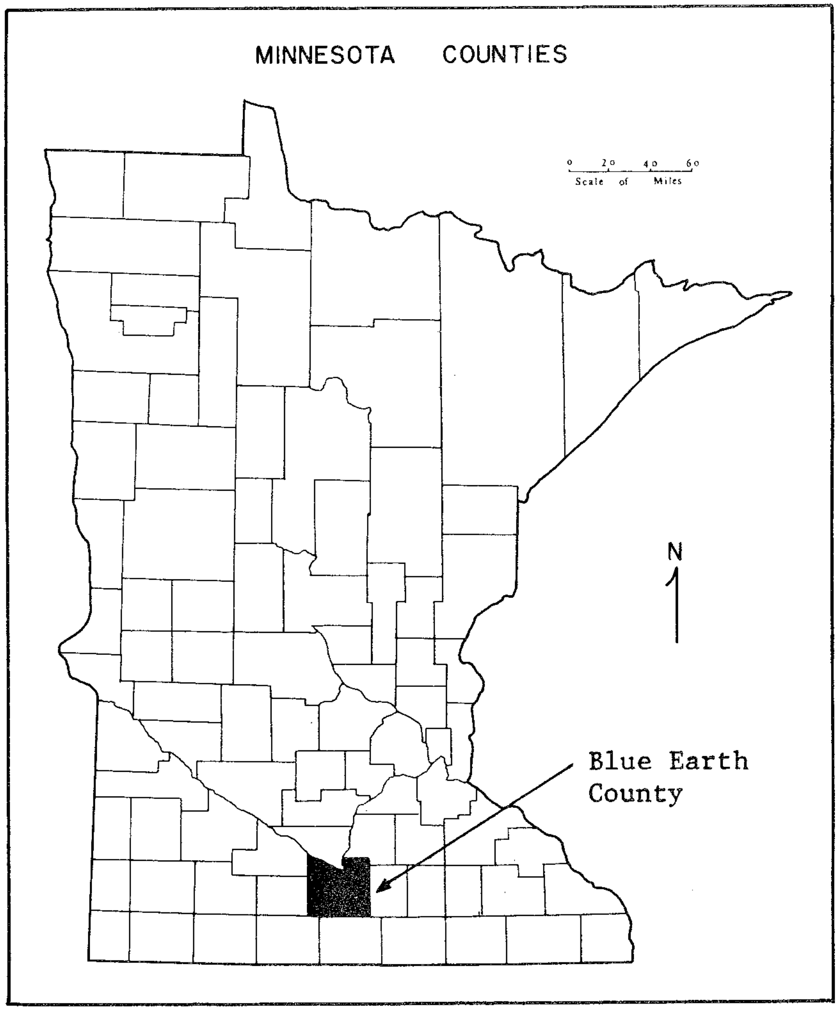

Figure 1. Position of Blue Earth County in Minnesota.

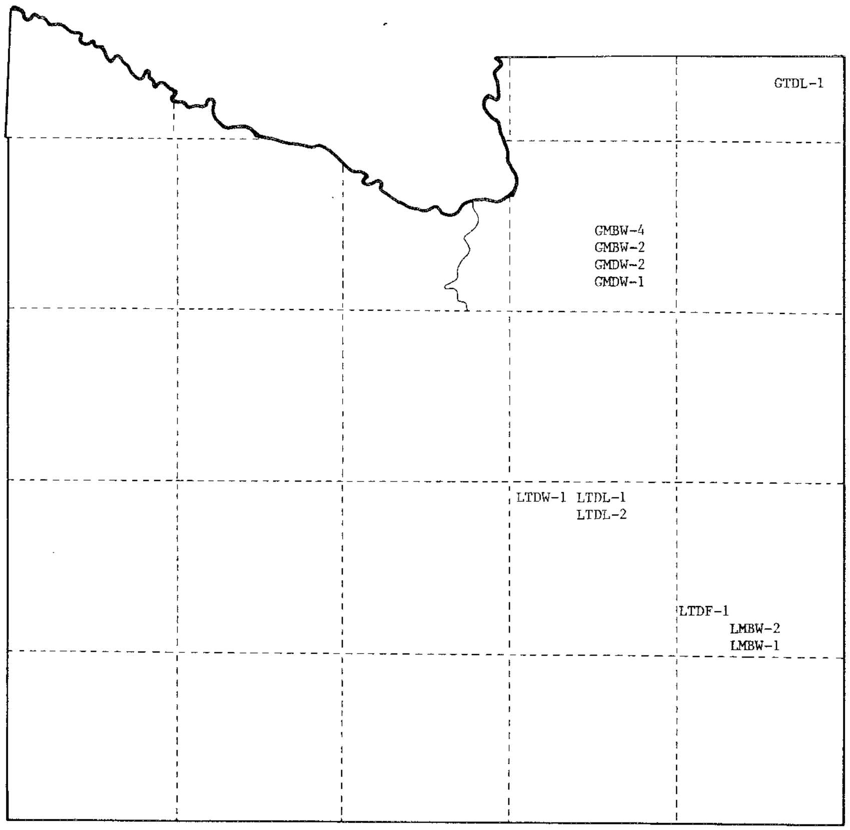

Figure 2. Position of each pond by code within Blue Earth County.

Codes were made up of four letters followed by a number. Numbers give further reference to ponds with similar characteristics which were found in the same vicinity. Letters are defined as follows:

1st letter: geomorphic setting (see geology)
- G=located within the glacial till region
- L=located within the lacustrine region

2nd letter: hydrologic setting
- M=marsh
- T=terrestrial

3rd letter: construction method
- D=excavated
- B=dynamited

4th letter: intended purpose
- W=wildlife
- L=livestock
- F=fish

Climate

The climate of Blue Earth County can be described as a cool, humid, continental climate with cold winters and warm summers. Warm, moist air from the Gulf of Mexico provides precipitation with an average annual rainfall of twenty-nine inches and an average annual snowfall of thirty-seven inches. Seventy percent of the rainfall occurs during the growing season. Other specific climatic information is given below (USDA, 1978).

Mean summer daily maximum temperature	80 to 85° F
Mean summer daily minimum temperature	50 to 60° F
Mean winter daily maximum temperature	29° F
Mean winter daily minimum temperature	9° F
Mean length of growing season	156 days

Geology

Most of Blue Earth County's topography is nearly level to gently undulating with an altitude range of 1,000 to 1,060 feet above sea level. The county was subjected to several coverings of ice sheets during the glacial period, of which much of their deposition cannot be readily seen. The final phase of the last glaciation, the Wisconsin, left behind an unsorted, shale-rich mantle of calcareous clay, sand, and gravel. The southern two-thirds of the county is dominated by lacustrine sediment, a remnant of Glacial Lake Minnesota. This sediment is primarily silty clay and silty loam. Only the northeastern quarter of the county consists of deciduous forest with the remainder being prairie (USGS, 1978).

Site Description

Note: All pond specifications below pertain to measurements taken during lowest water levels.

GTDL-1

This pond was located in the northeast corner of the county (NW¼ SE¼ sec. 24, T.109N., R.25W.). It was built as a watering pond for beef cattle and was therefore surrounded by grazed pasture. The pond was excavated in 1967 and measured 1.5m X 22m X 1.7m. To its west was a wetland which became inundated by water during the spring and fall, therefore coming in contact with the pond. Clarion-Storden-Estherville is the soil association of this pond with rolling to steep, well drained and somewhat excessively drained soils formed in medium-textured and course-textured glacial drift (USGS, 1978). Cattle were never seen using the pond but hoof prints at its entrance gave evidence of its occasional utilization. A species of *Lemna* covered the pond at various times throughout the sampling period.

GMDW-1, GMDW-1, GMBW-3, GMBW-4

This site was located east of the City of Mankato (SW¼ SW¼ sec. 23, T.108N., R.26W.) in a marsh with all four ponds constructed for wildlife. GMDW-1 and GMDW-2 were both excavated in 1976 and were 11m X 40m X 0.9m and 10m X 39m X 1.2m respectively. GMBW-3 and GMBW-4, on the other hand, were both dynamited and measured 10m X 54m X 1.1m and 10m X 53m X 1.0m respectively. Soybeans were grown east of this site on land sloping toward the marsh. The soil of the area is the Minnetonka-Kilkenny-Caron association with nearly level and moderately steep, very poorly drained, poorly drained and well drained soils formed in moderately fine-textured glacial till and organic material. The marsh sediment was characteristically peat. GMDW-1 and GMDW-2 were covered by *Lemna* throughout much of the season. All four ponds were surrounded by *Phalaris arundinacea* along with some *Typha* sp. around GMBW-3 and GMBW-4.

LMBW-1, LMBW-2

Two ponds were chosen in a marsh southeast of the City of Mankato (NE¼ NE¼ sec. 23, T.106N., R.25W.). Nine ponds in total were present in the wetland, and the two sampled were the second (LMBW-2) and the third (LMBW-1) ponds from the most northeast pond on the northwest side of the county ditch. These ponds were dynamited in 1969 with LMBW-1 being 9.5m X 19.5m X 1.0m and LMBW-2 being 10.5m X 20m X 1.0m. A corn field existed on the west edge of this site and a county ditch ran through the middle of the wetland. The soil for these two ponds was in the Marna-Gucken-Lura soil association with nearly level, very poorly drained, poorly drained and moderately well drained soils formed under prairie grasses in moderately fine and fine-textured material. The marsh was completely covered by water as a result of spring flooding prior to the sampling period, and at the time, the ponds were not discernible.

Both ponds were heavily covered with Lemna throughout much of the season, had steep embankments, and were surrounded by P. arundinacea which greatly reduced any effects freom wind.

LTDF-1

This was the only pond built for fish used in the study and was situated southeast of the City of Mankato (NW¼ SE¼ sec. 30, T.106N., R.25W.). The pond was excavated i.. 1971 and measured 40m X 210m X 5.2m. Tile draining an agricultural field north of the site emptied into the pond on the north side approximately fifteen meters from the west end. An effluent pipe existed on the west end and emptied into an open water wetland adjacent to the pond. Beuford-Lura-Shorewood makes up the soil association in this vicinity and is described as level, very poorly drained and moderately well drained soils formed in fine-textured lacustrine material which has greater than sixty percent clay. This was the only pond which exhibited and remained thermally stratified throughout the sampling period until turnover.

LTDL-1

Situated south of the City of Mankato (NW¼ NE¼ sec.4, T.106.N., R.26W.), this pond was excavated in 1981 and was 15m X 32m X 2.5m. The pond was built for beef cattle and therefore bordered by pasture. Drainage of agricultural land by tile emtied into the pond at the north-west corner and overflow drained via a pipe at the south end into cropland. The soils of the area can be described as Waldorf-Collinwood-Lura association with nearly level, very poorly drained, poorly drained and moderately drained soils formed in moderately fine and fine-textured lacustrine material underlain by medium-textured stratified lacustrine material. Cattle were never seen nor permitted to use the pond during the sampling season and had never made use of it prior to the study.

LTDL-2

This pond was constructed south of the City of Mankato (SE¼ NE¼ sec. 5, T.106N., R.26W.) very near LTDL-1. It was excavated in 1980 for beef cattle and had measurements of 19.5m X 41.5m X 2.4m. this pond was spring fed at the northeast corner and present at the north side was a steep bank protecting the pond from any wind from the north. Area soil characteristics are identical to those belonging to LTDL-1. Cattle did not frequent the surrounding pasture often, resulting in minimum grazing of the area. In addition, the cattle were never seen inhabiting the pond and to the owner's recollection, had never used it prior to the study.

LTDW-1

This site was located south of the City of Mankato (NW¼ NW¼ sec. 5, T.106N., R.26W.) and was constructed for wildlife. It was excavated in 1980 and measured 12m X 20.5m X 0.8m. The Big Cobb River flowed northward adjacent to the pond which overflowed its banks inundating the pond site prior to sampling. Hardwoods encompassed the pond with grasses immediately surrounding it, while a steep eroding bank resided on its north side, therefore minimizing any effects from wind. The soil description matches that of LTDL-1 and LTDL-2. A species of Chara grew abundantly along the edge of the pond during much of the season.

METHODS AND MATERIALS

Water Analysis

Field Methods

During the ice-free season of 1982, ponds were sampled from the third week in March until the third week in October approximately every three weeks except during the fall when sampling occurred every two weeks. All ponds were sampled at the surface, at the bottom, and in some ponds, in the middle depending on the depth of the pond. All collections took place at the location where the pond's depth was the greatest. The number of strata sampled for each pond remained constant throughout the season.

All samples were collected with a horizontal Van Dorn water sampler with a portion of the sample transfered into 300 ml BOD bottles previously rinsed with five percent hydrochloric acid for dissolved oxygen determinations, and the remaining portion stored in acid-rinsed one liter glass bottles for future chemical analysis. Dissolved oxygen samples were immediately fixed in the field with manganous-sulfate and alkalai-iodide.

Temperature readings were taken at each half-meter or meter, depending on pond depth, using a telethermometer (YSI Model 42SC).

Light penetration was measured using a Secchi disk. All ponds heavily covered with Lemna were given a reading of 0.0 meters.

Depth was recorded each sampling date with reference to changes in water levels measured on stationary posts placed in each pond prior to the sampling period.

Laboratory Methods

All analyses were conducted the same day as sampling except for occasional nitrate nitrogen determinations, in which samples were then stored overnight at $4^{0}C$ and treated with two milliliters of concentrated sulfuric acid.

Specific conductance was measured with a battery operated meter (Lab-line Instruments, Model MC-3) and recorded in umhos/cm.

Turbidity readings were taken, following mixing of the samples, using a turbidimeter (HACH, Model 2100A). Values were recorded in Jackson Turbidity Units (JTU), and a standard of sixty-nine JTU was used for calibration.

Chemical analyses were accomplished using standard methods (APHA, 1975) with samples remaining unfiltered. Dissolved oxygen (DO) was determined using the Winkler titration method (azide modification). Total Kjeldahl nitrogen (TKN), which includes both ammonia and organic nitrogen forms, was derived using the macro Kjeldahl procedure. Nitrate nitrogen (NO_3-N) concentrations were determined colorimetrically by the brucine method and were recorded as nitrate nitrogen (can be converted to nitrate by multiplying by 4.43). Phosphorus was measured as total orthophosphate phosphorus (PO_4-P) (unfiltered) and was analyzed colorimetrically using the stannous chloride method, in which a molybdophosphoric acid complex is reduced to molybdenum blue. Orthophosphate phosphorus can be converted to orthophosphate by multiplying by 3.06. Total orthophosphate determinations were performed the same day as collections, since lengthy storage may result in changes in orthophosphate concentrations, and ultimately in imprecision in the derivations (Johnson et al., 1975).

Sediment Analysis

Field Methods

Cores, using a Livingston Corer, were taken at each pond's maximum depth during February of 1983. These cores were brought back to the lab and frozen to be later analyzed for total Kjeldahl nitrogen, total phosphorus, and percent organic matter.

Laboratory Methods

After the cores were thawed, individual subsamples from each were chosen based upon appearance and texture, and were oven dried at 55^{0}C for thirty-six hours. Each sample was then ground in a Wiley mill and passed through a twenty mesh (0.5mm) screen, and then subjected to an additional eighteen hours of drying followed by storage in sterilized plastic bags.

The determination of total Kjeldahl nitrogen followed that of Black (1965), and was further modified by using methylene blue and methyl red as indicators.

Total phosphorus concentrations were attained by the digestion of one gram samples with perchloric acid, followed by spectrophotometric determination of phosphorus using acid-free vanadate-molybdate as a reagent (Tandon et al., 1968). Interference from ferric ions is avoided via this method.

Samples were analyzed for percent organic matter by placing each sample in a tared crucible and oven dried at 95^{0}C for twenty-four hours. The dried samples were then burned in a muffle furnace at 550^{0}C for one and one-half hours to determine the organic percentage.

Biological Sampling

Each pond was sampled qualitatively for fish, benthos, zooplankton, snails, and aquatic macrophytes during the latter part of the summer.

Zooplankton were sampled before sunrise using a five liter Juday plankton trap except in those ponds one meter or less in depth, in which a plankton net was used. An Ekman dredge was employed in collecting chironomids at several locations, while fish and the remaining benthos were collected via nets. Fish, zooplankton, and snails were identified using Eddy and Hodson's (1962) taxonomic keys. Benthic nomenclature was derived from Hilsenhoff (1975), Merrit and Cummins (1978) and McCafferty (1981). Aquatic macrophytes were identified using keys by Prescott (1969) and Fasset (1960).

Morphometry

All ponds were measured for length, width, and depth when water levels were at their seasonal minimum.

Statistical Analysis

Data analysis involved the application of the SPSS (Statistical Package for the Social Sciences) package (Nie et al., 1975) using a UNIVAC 1100/80 computer. The T-test was applied to investigate whether or not significant differences between means existed, while Pearson product-moment correlation coefficients were computed for linear correlation analysis. Data were clumped together into seasonal groups: an early season made up of the first four sampling dates, and a late season comprised of the following four dates. This scheme was utilized in many of the statistical procedures. Cut-off dates for defining the seasons were based upon definite changes in dissolved oxygen and total Kjeldahl nitrogen concentrations in the bottom waters which occurred in all ponds at approximately the same sampling date. Various descriptive statistics were also calculated when needed. A significance level of 0.05 was utilized unless otherwise indicated.

PHYSIO-CHEMICAL ANALYSIS

Results

Water Analysis

Raw data for each sampling date can be found in Appendix B.

Dissolved oxygen. Some considerable differences in dissolved oxygen concentrations were evident between surface and bottom samples, and also between the early and late seasons (Table 3). In a majority of the ponds, bottom samples displayed lower oxygen levels than did those at the surface. Exceptions to this were apparent in ponds LTDL-2 during the early season, and in LTDL-1 and LTDW-1 during the late season in which mean values contradicted the above trend. LTDW-1 showed considerably greater concentrations during the late season than in the early season. The greatest dissimilarity between

Table 3. Seasonal means for dissolved oxygen concentrations (ppm) for both surface and bottom samples.

		EARLY SEASON			LATE SEASON		
SITE	STRATUM	MEAN	SD	RANGE	MEAN	SD	RANGE
GTDL-1	surface	5.79	0.70	5.22-6.81	6.42	2.67	2.97-9.36
	bottom	2.92	2.52	0.00-5.43	1.26	2.18	0.00-4.51
GMDW-1	surface	4.05	2.18	2.19-7.19	2.33	4.56	0.00-9.16
	bottom	2.43	2.29	0.29-5.18	1.83	3.65	0.00-7.30
GMDW-2	surface	5.99	1.66	4.46-8.30	5.13	4.47	0.30-10.89
	bottom	3.26	3.01	0.98-7.61	1.05	1.37	0.00-2.99
GMBW-3	surface	7.40	0.64	6.81-8.28	5.57	1.28	4.39-6.76
	bottom	5.59	2.24	2.45-7.52	4.25	0.77	3.58-5.17
GMBW-4	surface	8.32	1.00	7.52-9.71	6.49	2.65	4.09-9.14
	bottom	5.11	2.81	1.23-7.53	3.93	1.65	2.36-6.25
LMBW-1	surface	5.01	2.74	1.13-7.44	0.94	1.88	0.00-3.76
	bottom	3.61	3.10	0.00-7.13	0.00	0.00	0.00-0.00
LMBW-2	surface	4.19	3.72	0.82-8.64	0.00	0.00	0.00-0.00
	bottom	3.20	4.10	0.00-9.07	0.00	0.00	0.00-0.00
LTDF-1	surface	8.19	0.70	7.53-8.96	8.28	3.09	6.00-12.83
	bottom	0.41	0.51	0.00-1.07	0.00	0.00	0.00-0.00
LTDL-1	surface	9.51	2.37	6.72-11.51	9.37	1.14	8.19-10.66
	bottom	8.45	2.28	5.71-11.24	9.85	1.37	8.03-11.32
LTDL-2	surface	6.63	1.95	4.70-8.66	7.94	1.87	5.28-9.66
	bottom	7.67	0.68	6.69-8.17	6.97	2.31	3.65-9.00
LTDW-1	surface	5.83	1.05	4.87-6.87	8.97	3.20	6.16-13.34
	bottom	4.54	0.75	4.01-5.64	9.42	4.53	5.07-14.47

surface and bottom concentrations occurred in LTDF-1 (8.19 and 0.41 ppm respectively during the early season, and 8.28 and 0.00 ppm respectively during the late season) while the smallest differences were found among both LTDL-1 and LTDL-2.

Over half of the ponds became anoxic near the bottom at some time during the season, and included GTDL-1, GMDW-1, GMDW-2, LMBW-1, LMBW-2, and LTDF-1. LMBW-2 was anoxic throughout the entire water column during the late season until samples from the last sampling date (October 18) indicated an increase at the surface. LMBW-2 showed similar results by August 23 and until October 18. GMDW-1 was the only other pond to become entirely anoxic during the sampling period.

Total Kjeldahl nitrogen. Total Kjeldahl nitrogen exhibited some differences with respect to both depth and season (Table 4). In general, greater concentrations were found nearer the bottom than at the surface, with the greatest deviation between the two occurring in LTDF-1. This was most evident during the late season (0.88 ppm at the surface and 10.77 ppm near the bottom). GMBW-3, LTDL-1, LTDL-2, and LTDW-1 showed very little differences between surface and bottom concentrations during the late season as compared to the early season with the exception of LTDW-1.

When considering ponds which were not definitely stratified (all but LTDF-1), those built within a marsh tended to have higher levels than did terrestrial ponds. Surface and bottom mean seasonal concentrations for marsh ponds as a group were 1.40 and 1.53 ppm respectively for the early season, and 2.21 and 2.66 ppm respectively during the late season; whereas concentrations within terrestrial ponds as a group were 0.80 and 0.87 ppm respectively during the early season, and 1.12 and 1.27 ppm respectively during the late season. In addition, GMDW-1, LMBW-1, and LMBW-2 showed greater concentrations than the remaining marsh ponds; just the opposite as was found in regard to dissolved oxygen.

Nitrate nitrogen. Few trends, if any, appeared from data concerning nitrate nitrogen (Table 5). Each of the ponds with entering tile drainage (LTDF-1 and LTDL-1) exhibited the greatest concentrations, with LTDL-1 by far the most extreme (24.27 and 22.49 ppm for seasonal means at the surface and bottom respectively during the early season). In addition, concentrations in these two ponds decreased significantly by the late season, except for a small increase in LTDL-1 on October 21. The lowest overall concentrations were evident among LTDL-2 and LTDW-1, with very little change in levels with respect to both depth and season occurring in LTDW-1. In the case of LMBW-1 and LMBW-2, which were both constructed within the same vicinity, LMBW-1, during the early season, began at levels much greater than the latter, followed by nearly identical concentrations during the late season (Figure 3). This was very unexpected since this site was completely covered with water from spring flooding by the county ditch, resulting in both ponds being filled with similar water. A sharp increase, uncharacteristic of the other ponds, was detected in GMDW-2 on June 8, but levels returned to concentrations similar to those during the early season.

Table 4. Seasonal means for total Kjeldahl nitrogen concentrations (ppm) for both surface and bottom samples.

		EARLY SEASON			LATE SEASON		
SITE	STRATUM	MEAN	SD	RANGE	MEAN	SD	RANGE
GTDL-1	surface	0.89	0.28	0.49-1.15	1.87	0.83	1.25-3.09
	bottom	1.03	0.23	0.83-1.36	2.50	1.16	1.49-4.15
GMDW-1	surface	1.15	0.30	0.75-1.45	2.56	0.44	1.94-2.93
	bottom	1.32	0.22	1.15-1.63	3.14	0.81	2.05-3.88
GMDW-2	surface	1.18	0.13	1.02-1.32	1.92	0.20	1.64-2.11
	bottom	1.34	0.16	1.11-1.46	2.26	0.34	1.94-2.70
GMBW-3	surface	1.31	0.13	1.13-1.42	2.05	0.35	1.61-2.46
	bottom	1.29	0.13	1.10-1.38	2.09	0.27	1.70-2.28
GMBW-4	surface	1.55	0.20	1.37-1.80	2.22	0.14	2.05-2.39
	bottom	1.59	0.27	1.33-1.94	2.41	1.82	2.15-2.54
LMBW-1	surface	1.51	0.41	1.08-1.95	2.11	0.33	1.92-2.49
	bottom	1.69	0.48	1.31-2.31	3.28	0.52	2.90-3.88
LMBW-2	surface	1.71	0.32	1.37-2.01	2.37	0.27	2.18-2.68
	bottom	1.97	0.80	1.25-3.09	2.78	0.28	2.59-3.10
LTDF-1	surface	0.95	0.09	0.81-1.01	0.88	0.45	0.37-1.16
	bottom	3.62	1.69	2.01-5.86	10.77	4.46	5.65-13.82
LTDL-1	surface	0.72	0.40	0.21-1.19	1.11	0.64	0.43-1.70
	bottom	0.89	0.37	0.67-1.31	1.13	0.68	0.37-1.69
LTDL-2	surface	0.75	0.12	0.67-0.93	0.80	0.52	0.21-1.15
	bottom	0.72	0.19	0.52-0.97	0.76	0.46	0.23-1.03
LTDW-1	surface	0.84	0.18	0.70-1.08	0.68	0.55	0.29-1.07
	bottom	0.84	0.21	0.64-1.11	0.69	0.50	0.11-0.98

Table 5. Seasonal means for nitrate nitrogen concentrations (ppm) for both surface and bottom samples.

		EARLY SEASON			LATE SEASON		
SITE	STRATUM	MEAN	SD	RANGE	MEAN	SD	RANGE
GTDL-1	surface	0.18	0.13	0.06-0.31	0.30	0.14	0.13-0.47
	bottom	0.25	0.10	0.11-0.31	0.31	0.11	0.17-0.43
GMDW-1	surface	0.17	0.03	0.14-0.19	0.30	0.04	0.26-0.35
	bottom	0.23	0.11	0.11-0.38	0.29	0.02	0.28-0.33
GMDW-2	surface	0.37	0.36	0.13-0.90	0.25	0.06	0.17-0.29
	bottom	0.45	0.31	0.20-0.89	0.34	0.06	0.25-0.40
GMBW-3	surface	0.16	0.03	0.14-0.20	0.25	0.04	0.21-0.29
	bottom	0.23	0.12	0.14-0.40	0.23	0.06	0.15-0.28
GMBW-4	surface	0.31	0.17	0.21-0.56	0.38	0.10	0.29-0.48
	bottom	0.26	0.11	0.18-0.41	0.36	0.12	0.24-0.51
LMBW-1	surface	0.42	0.51	0.12-1.18	0.28	0.09	0.17-0.37
	bottom	0.47	0.52	0.09-1.22	0.31	0.11	0.20-0.45
LMBW-2	surface	0.15	0.04	0.10-0.11	0.31	0.01	0.30-0.32
	bottom	0.16	0.06	0.11-0.26	0.32	0.02	0.29-0.34
LTDF-1	surface	4.49	3.04	0.85-7.67	1.04	1.54	0.06-3.32
	bottom	0.56	0.76	0.10-1.70	0.18	0.14	0.04-0.37
LTDL-1	surface	24.27	5.11	16.66-27.71	9.71	4.25	5.23-15.35
	bottom	22.49	4.52	17.87-27.16	10.39	5.21	5.42-17.14
LTDL-2	surface	0.08	0.07	0.02-0.19	0.03	0.01	0.02-0.04
	bottom	0.03	0.02	0.01-0.04	0.03	0.01	0.02-0.04
LTDW-1	surface	0.04	0.01	0.03-0.06	0.03	0.01	0.02-0.05
	bottom	0.04	0.01	0.03-0.04	0.04	0.01	0.03-0.06

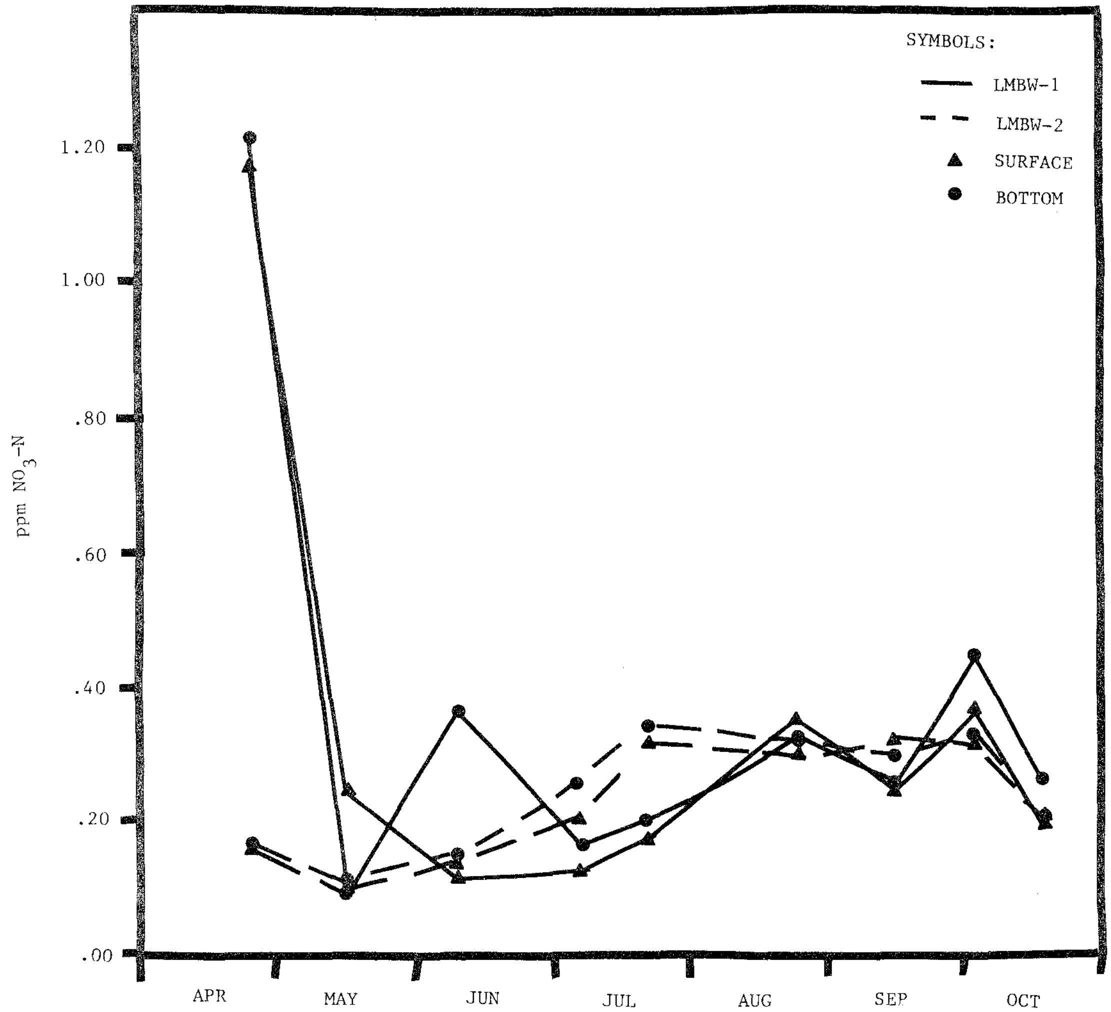

Figure 3. Changes in nitrate nitrogen concentrations throughout the season within LMBW-1 and LMBW-2.

Total orthophosphate. In all ponds, mean seasonal total orthophosphate concentrations were greater nearer the bottom than at the surface, except in LTDL-2 and LTDW-1, where levels at each stratum were approximately the same, if not greater, at the surface (Table 6). In addition, mean concentrations during the late season were higher. Ponds not conforming to this included GMBW-3, GMBW-4, LMBW-2, and LTDW-1. The most significant difference between surface and bottom samples was again found in LTDF-1, while extremely drastic changes throughout the water column were evident in LTDL-1 as compared to LTDL-2 (Figure 4). Of the marsh ponds built in the glacial till region, GMBW-3 and GMBW-4 revealed definitely lower concentrations than did GMDW-1 and GMDW-2. Highest levels near the bottom were prevalent in those which become anoxic (GTDL-1, GMDW-1, GMDW-2, LMBW-1, LMBW-2, and LTDF-1).

Turbidity. Some definite trends in turbidity were observed among the ponds; the most common being that nearly all were more turbid nearer the bottom, and also during the late season with reference to mean seasonal readings (Table 7). The greatest mean values, with respect to bottom samples, existed within LMBW-1 and LMBW-2, as well as in LTDF-1. In addition, LTDF-1 showed the greatest discrepancy between surface and bottom samples.

Ponds fed by tile drainage showed increases in turbidity at the very end of the sampling period. In LTDL-1, surface and bottom readings were 4.5 and 2.5 JTU respectively on October 10, and 36.0 and 40.5 JTU respectively on October 21. The other tile fed pond, LTDF-1, accompanied this with its surface readings increasing from 5.0 JTU on October 3 to 20.0 JTU on October 20.

Specific conductance. Patterns regarding conductivity were rare among the ponds as a group, but those constructed within the same vicinity shared some common characteristics (Table 8). GMBW-3 and GMBW-4, unlike GMDW-1 and GMDW-2, together decreased overall throughout the season, while LMBW-1 and LMBW-2 both increased dramatically and reached their maximum around mid-season. Highest values were also found among LMBW-1 and LMBW-2 with values peaking above 1,000 umhos/cm near the bottom at times. Readings were considerably greater in LTDL-2 than in LTDL-1, primarily due to a major decrease in conductance within LTDL-1 during the late season.

Light penetration. Definite seasonal differences were evident among Secchi disk readings (Table 9). Light penetration was considerably less during the late season within all ponds, with LTDF-1, LTDL-1, and LTDW-1 having the highest values throughout much of the season. GTDL-1 was the only terrestrial pond not complying to this, but instead showed values similar to the marsh ponds. At times, light reached the bottom among LTDL-1, LTDL-2, and LMBW-2, as it did six of the nine sampling dates within LTDW-1. Because of extensive blooms of Lemna, LMBW-2 was given a reading of 0.0 meters for the entire late season, while identical values were also given to GTDL-1, GMBW-1, and LMBW-1 at various times during the sampling period for the same reason.

Linear correlations. Correlation coefficients were computed in the following manner: (1) for each category of ponds (excavated, terrestrial, etc.); (2) for all eleven ponds together; (3) for each individual pond.

Table 6. Seasonal means for total orthophosphate concentrations (ppm) for both surface and bottom samples.

SITE	STRATUM	MEAN	SD	RANGE	MEAN	SD	RANGE
GTDL-1	surface	0.135	0.053	0.074-0.203	0.173	0.131	0.099-0.370
	bottom	0.450	0.297	0.213-0.848	0.607	0.314	0.156-0.883
GMDW-1	surface	0.172	0.097	0.086-0.305	0.372	0.157	0.156-0.523
	bottom	0.272	0.178	0.074-0.451	0.555	0.348	0.164-0.996
GMDW-2	surface	0.106	0.081	0.025-0.210	0.118	0.046	0.078-0.164
	bottom	0.221	0.208	0.040-0.509	0.430	0.280	0.197-0.828
GMDW-3	surface	0.042	0.027	0.020-0.076	0.040	0.009	0.029-0.049
	bottom	0.065	0.050	0.019-0.118	0.039	0.007	0.033-0.045
GMBW-4	surface	0.073	0.053	0.022-0.121	0.041	0.015	0.025-0.058
	bottom	0.116	0.098	0.042-0.251	0.043	0.015	0.029-0.057
LMBW-1	surface	0.230	0.141	0.044-0.347	0.296	0.118	0.176-1.440
	bottom	0.386	0.395	0.054-0.953	0.750	0.414	0.437-1.350
LMBW-2	surface	0.244	0.200	0.066-0.501	0.460	0.109	0.336-0.602
	bottom	0.396	0.389	0.062-0.899	0.606	0.169	0.447-0.840
LTDF-1	surface	0.060	0.046	0.011-0.102	0.038	0.025	0.010-0.066
	bottom	0.922	0.746	0.158-1.827	2.939	0.755	1.966-3.562
LTDL-1	surface	0.037	0.033	0.005-0.075	0.033	0.029	0.011-0.075
	bottom	0.048	0.043	0.005-0.085	0.089	0.124	0.017-0.273
LTDL-2	surface	0.009	0.003	0.005-0.011	0.010	0.001	0.009-0.011
	bottom	0.007	0.002	0.004-0.008	0.008	0.004	0.003-0.012
LTDW-1	surface	0.050	0.045	0.010-0.099	0.026	0.026	0.002-0.061
	bottom	0.055	0.034	0.021-0.096	0.017	0.014	0.003-0.034

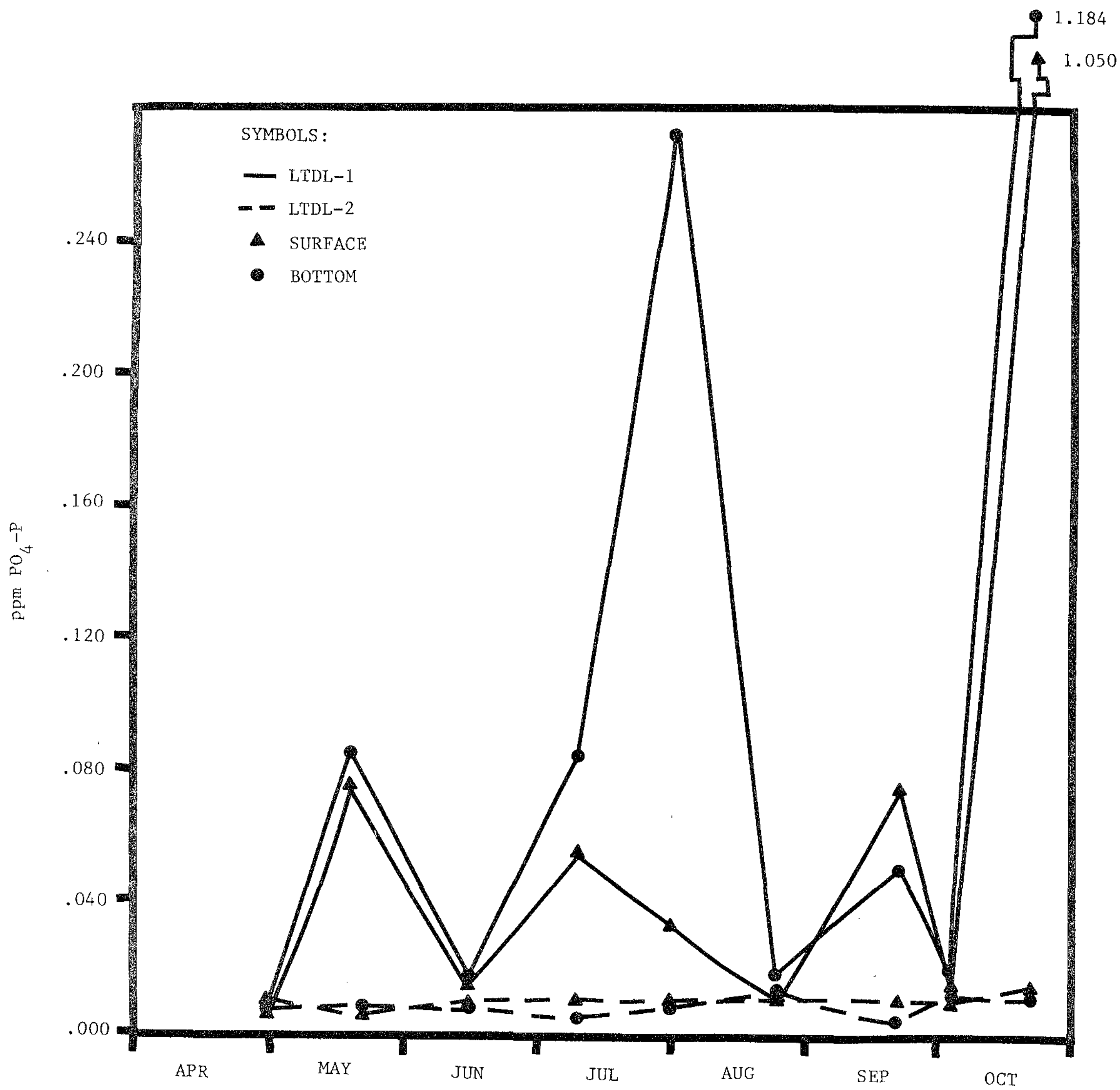

Figure 4. Changes in total orthophosphate concentrations throughout the season within LTDL-1 and LTDL-2.

Table 7. Seasonal means for turbidity (JTU) for both surface and bottom samples.

		EARLY SEASON			LATE SEASON		
SITE	STRATUM	MEAN	SD	RANGE	MEAN	SD	RANGE
GTDL-1	surface	20.8	32.9	3.0-70.0	17.3	7.8	9.0-27.5
	bottom	37.0	25.2	14.0-72.5	33.3	13.6	14.0-44.5
GMDW-1	surface	1.9	0.5	1.5-2.5	5.4	1.8	3.0-7.0
	bottom	4.6	1.8	2.5-7.0	6.3	1.3	4.5-7.5
GMDW-2	surface	3.5	1.3	2.0-5.0	7.4	2.7	4.0-10.5
	bottom	5.1	3.4	2.5-10.0	11.3	3.1	7.5-15.0
GMBW-3	surface	5.1	2.1	2.5-7.5	15.8	4.5	9.5-19.5
	bottom	6.4	2.7	3.5-10.0	16.3	4.4	10.0-20.0
GMBW-4	surface	5.9	2.8	2.5-9.0	10.4	4.0	6.5-14.5
	bottom	6.4	3.0	3.0-10.0	10.9	3.6	5.5-13.0
LMBW-1	surface	4.4	2.8	2.0-7.0	31.5	32.0	2.0-69.0
	bottom	21.4	31.8	2.5-69.0	83.2	16.5	61.0-99.9
LMBW-2	surface	7.3	5.0	2.0-14.0	24.6	17.1	6.5-47.0
	bottom	17.0	21.2	3.5-48.5	42.5	13.1	28.0-58.0
LTDF-1	surface	3.9	2.5	2.0-7.5	3.4	1.2	2.5-5.0
	bottom	26.4	26.5	5.0-62.0	68.6	2.9	65.0-72.0
LTDL-1	surface	2.4	0.9	1.5-3.5	3.1	1.1	2.0-4.5
	bottom	3.9	3.0	1.0-8.0	3.1	0.8	2.5-4.0
LTDL-2	surface	2.0	0.7	1.0-2.5	2.0	0.4	1.5-2.5
	bottom	1.9	0.6	1.0-2.5	2.4	0.8	1.5-3.0
LTDW-1	surface	1.4	0.5	1.0-2.0	4.9	4.2	1.0-10.0
	bottom	4.3	4.9	1.0-11.5	6.8	4.4	2.0-11.0

Table 8. Seasonal means for conductivity (umhos/cm) for both surface and bottom samples.

		EARLY SEASON			LATE SEASON		
SITE	STRATUM	MEAN	SD	RANGE	MEAN	SD	RANGE
GTDL-1	surface	456	146	280-590	423	7	415-430
	bottom	461	152	255-590	446	42	400-495
GMDW-1	surface	568	108	420-680	726	98	650-870
	bottom	595	77	500-685	715	60	645-780
GMDW-2	surface	593	119	510-765	575	39	540-620
	bottom	599	72	520-695	626	31	585-650
GMBW-3	surface	630	93	520-735	484	52	425-550
	bottom	616	102	495-735	489	55	420-555
GMBW-4	surface	709	96	605-800	543	47	500-605
	bottom	734	123	605-880	561	60	505-640
LMBW-1	surface	668	33	630-700	766	26	740-795
	bottom	780	234	640-1130	859	124	750-1025
LMBW-2	surface	703	85	625-815	868	71	800-960
	bottom	739	128	635-925	950	176	830-1210
LTDF-1	surface	509	84	385-570	451	43	410-505
	bottom	623	30	590-650	680	15	665-700
LTDL-1	surface	753	52	700-800	543	156	410-765
	bottom	744	59	690-800	541	201	400-835
LTDL-2	surface	845	36	795-880	815	37	795-870
	bottom	861	46	795-900	841	74	765-930
LTDW-1	surface	770	93	655-870	588	33	545-625
	bottom	776	70	690-845	585	51	515-625

Table 9. Seasonal means for Secchi disk readings in meters.

	EARLY SEASON			LATE SEASON		
SITE	MEAN	SD	RANGE	MEAN	SD	RANGE
GTDL-1	0.6	0.7	0.0-1.6	0.4	0.2	0.0-0.5
GMDW-1	0.6	0.5	0.0-1.2	0.2	0.2	0.0-0.4
GMDW-2	0.8	0.2	0.6-0.9	0.5	0.2	0.3-0.7
GMBW-3	0.6	0.1	0.5-0.7	0.3	0.1	0.3-0.4
GMBW-4	0.5	0.1	0.4-0.7	0.4	0.1	0.3-0.5
LMBW-1	0.9	0.2	0.6-1.1	0.2	0.4	0.0-0.8
LMBW-2	0.7	0.6	0.0-1.2	0.0	0.0	0.0-0.0
LTDF-1	1.5	0.5	0.9-2.1	1.1	0.2	0.9-1.3
LTDL-1	1.9	0.8	0.8-2.6	1.3	0.6	0.9-2.1
LTDL-2	1.6	0.6	1.1-2.4	1.5	0.6	1.0-2.2
LTDW-1	1.6	0.4	1.1-1.9	0.7	0.2	0.5-0.9

Comparisons were made between pond categories to determine whether or not a statistically significant positive correlation was evident for one condition, while a significant negative correlation existed within its counterpart concerning the same parameter (Table 10). Significance levels were set at 0.05.

When dynamited ponds were compared with ponds that were excavated, total Kjeldahl nitrogen, total orthophosphate, and turbidity levels were significantly and positively correlated with depth within the excavated ponds. In other words, the deeper the pond the greater the above concentrations. On the other hand, these associations were significantly negative within the dynamited ponds. Turbidity with conductivity was significantly negative within excavated ponds, whereas the dynamited ponds showed a significant positive correlation.

Differences in correlation direction were also observed when ponds within the glacial till region were compared with those within the lacustrine region. A significant positive correlation existed between depth and total Kjeldahl nitrogen among the lacustrine ponds, but was significantly negative among those within the glacial till region. Turbidity was positively correlated with conductivity within the lacustrine ponds, but negatively associated within the glacial till ponds. In addition, a significant negative relationship concerning total Kjeldahl nitrogen with nitrate nitrogen was evident within the lacustrine ponds, but was found to be positively correlated within the glacial till ponds.

Correlation direction regarding total Kjeldahl nitrogen with depth was again dissimilar when considering marsh and terrestrial ponds. Within the terrestrial ponds, the correlation was significantly positive, whereas in the marsh ponds, the correlation was significantly negative. Turbidity was negatively correlated with conductivity with regard to terrestrial ponds, but was positively associated among marsh ponds. Total orthophosphate was also found to be positively correlated with depth within the terrestrial ponds, and negatively within the marsh ponds.

Differences were also found between these categories with respect to dissolved oxygen with both conductivity and depth. Correlations within terrestrial ponds were significantly positive for dissolved oxygen with conductivity, whereas within marsh ponds, they were significantly negative. When correlated with depth, terrestrial ponds displayed a significant negative correlation, whereas marsh ponds showed a significant positive association.

Correlations were relatively weak when data from all ponds were analyzed together, although a coefficient of .8593 ($P < .01$) was determined for total Kjeldahl nitrogen with total orthophosphate, indicating a rather strong positive association (Figure 5). one of the few strong associations found when categories were analyzed, concerned these two parameters (all $P=.000$). A coefficient of .8983 was found among excavated ponds versus .5961 within dynamited ponds, .9126 for terrestrial ponds versus .6024 for marsh ponds, and .9290 within lacustrine ponds versus .3143 within glacial till ponds. In

Table 10. Directions of significant correlations concerning water quality parameters in which correlations were opposite in direction between categories being contrasted ($P<.05$). (+) = significant positive correlation, (–) = significant negative correlation.

CATEGORY	TKN/Depth	PO_4-P/Depth	Turb/Depth	DO/Depth	Turb/Cond	DO/Cond	TKN/NO_3-N
Excavated	+	+	+		–		
Dynamited	–	–	–		+		
Glacial Till	–				–		+
Lacustrine	+				+		–
Marsh	–	–		+	+	–	
Dynamited	+	+		–	–	+	

	TKN	PO_4-P	DO	TURBIDITY
DEPTH	GTDL-1 - GMDW-2 - GMBW-3 - GMBW-4 -			
TURBIDITY	GMDW-2 + GMBW-3 + GMBW-4 + LMBW-1 + LMBW-2 + LTDF-1 +	LTDF-1 +		
DO	LMBW-1 - LMBW-2 -			
PO_4-P	All + Excavated + Lacustrine + Marsh + LMBW-2 + LTDF-1 +			

Figure 5. Summary of strong correlations ($-.74 \geq r \geq .75$) found among individual, as well as categories, of ponds ($P<.01$) concerning water quality parameters. (+) = positive correlation, (-) = negative correlation.

regard to these same parameters, individual ponds with strong correlations included LMBW-2 (r=.9260), although dynamited, and LTDF-1 (r=.9853); both ponds which were located within the lacustrine region (P=.000 for each).

Correlations were found to be strong among individual ponds which were characteristically similar (Figure 5). For example, it was observed only among ponds within the glacial till region, that the more shallow the pond the greater the total Kjeldahl nitrogen concentration. Although this was mentioned earlier to be significantly negative within this category of ponds, strong relationships were prevalent among GTDL-1 (r=-.8855), GMDW-2 (r=-.8839), GMBW-3 (r=-.8243), and in GMBW-4 (r=-.7928). A coefficient of -.5394 was determined for all glacial till ponds as a group, meaning that proportional changes between the parameters for each of the above ponds individually were different than the changes within the other three. Lacustrine ponds displayed much weaker if not positive correlations.

A similar pattern was found concerning total Kjeldahl nitrogen with turbidity. Individual marsh ponds displayed high coefficients, and included the following ponds (P=.000): GMDW-2 (r=.8874), GMBW-3 (r=.9638), GMBW-4 (r=.7758), LMBW-1 (r=.8514), and LMBW-2 (r=.8743). The correlation for GMDW-1 was somewhat weaker than those above (r=.5628, $P < .05$), and a correlation of .5983 ($P < .01$) was determined for all marsh ponds together. Individually, terrestrial ponds showed much weaker correlations, except within LTDF-1 which had a coefficient of .8700 ($P < .01$).

Total orthophosphate increased along with turbidity in both ponds with entering tile drainage. LTDF-1 displayed a coefficient of .9318 ($P < .01$), while the association in LTDL-1 was stronger (r=.9796, $P < .01$).

Dissolved oxygen was negatively correlated with total Kjeldahl nitrogen, but a strong relationship was apparent only in LMBW-1 and LMBW-2. Coefficients for each respectively were -.7995 and -.7446 ($P < .01$).

<u>T-tests</u>. T-tests were run to determine if differences in water quality parameters between seasonal means at both surface and bottom portions of the water column were significant for the following comparisons: (1) excavated ponds against dynamited ponds; (2) ponds located within the glacial till region against those located within the lacustrine region; (3) marsh ponds against terrestrial ponds. A summary of the results is found in Table 11. Because of the effects of stratification on water chemistry, LTDF-1 was not included in this analysis.

With respect to dissolved oxygen, excavated ponds were significantly higher in levels throughout the water column during the late season than were dynamited ponds. The mean surface concentration for excavated ponds was 6.69 ppm, and 3.25 ppm for dynamited ponds, while bottom concentrations of 5.06 and 2.04 ppm were displayed by each respectively. Terrestrial ponds were significantly greater in concentration than marsh ponds during the late season, with surface means of 8.17 and 3.41 ppm, and bottom means of 6.87 and 1.84 ppm for each respectively. Concentrations near the bottom during the early season were

Table 11. T-test results concerning water quality parameters between pond categories. Upper case letters indicate which of the categories being compared had significantly greater means (P=.05). Does not include LTDF-1.

Categories	Season	Depth	DO	TKN	NO_3-N	PO_4-P	Turb	Cond	Light penet.
Excavated (D)	early	surface		B					D
		bottom		B					
vs									
Dynamited (B)	late	surface	D	B			B		D
		bottom	D	B			B		
Glacial till (G)	early	surface			L			L	L
		bottom						L	
vs									
Lacustrine (L)	late	surface		G				L	L
		bottom	L	G				L	
Marsh (M)	early	surface		M	T	M			T
		bottom	T	M					
vs									
Terrestrial (T)	late	surface	T	M		M	M		T
		bottom	T	M		M	M		

also significantly higher within the terrestrial ponds (5.89 ppm) as compared to marsh ponds (3.87 ppm). Lacustrine ponds displayed significantly greater concentrations only during the late season and near the bottom with a mean of 5.25 ppm, whereas 2.46 ppm was the mean within glacial till ponds.

Both dynamited and marsh ponds were significantly greater in regard to total Kjeldahl nitrogen concentrations throughout the water column for the entire season than were their counterparts. Concerning dynamited and excavated ponds respectively, early season means were 1.52 and 0.92 ppm near the surface, and 1.64 and 1.03 ppm near the bottom; while during the late season, surface means were 2.18 and 1.62 ppm, and 2.58 and 1.87 ppm near the bottom respectively. In a similar situation, an early season mean of 1.40 ppm for marsh ponds versus 0.80 ppm for terrestrial ponds existed near the surface, while near the bottom, marsh ponds were again significantly greater with a mean of 1.53 ppm compared to a mean of 0.87 ppm within the terrestrial ponds. During the late season, surface means within marsh and terrestrial ponds were 2.20 and 1.21 ppm, and near the bottom were 2.63 and 1.36 ppm respectively.

Ponds within the glacial till region were significantly greater in total Kjeldahl nitrogen throughout the water column than were lacustrine ponds, but only during the late season. Means at the surface were 2.12 ppm among glacial till ponds and 1.47 ppm within lacustrine ponds, while near the bottom, means were 2.48 and 1.73 ppm within each respectively.

Significant differences in nitrate nitrogen concentrations were tenuous with exception to lacustrine ponds and terrestrial ponds, which were both significantly higher in levels near the surface than were their counterparts. This was evident during the early season only. A mean concentration of 4.99 ppm was found among the lacustrine ponds versus 0.24 ppm within the glacial till ponds. Terrestrial ponds were significantly greater with a mean of 6.14 ppm, whereas the mean within all marsh ponds was 0.26 ppm.

Total orthophosphate concentrations were significantly different, but only in regard to marsh and terrestrial ponds. Marsh ponds displayed a greater mean (0.14 ppm) during the early season near the surface, while a mean of 0.06 ppm prevailed among the terrestrial ponds. Marsh ponds were again significantly greater in levels during the late season, and this time throughout the water column. Concentrations within marsh and terrestrial sites respectively were 0.22 and 0.06 ppm near the surface, and 0.40 and 0.18 ppm near the bottom.

Both dynamited and marsh ponds were significantly greater in turbidity during the late season than either excavated or terrestrial ponds respectively. Means near the surface were higher within ponds that were dynamited (20.6 JTU) compared to excavated ponds (6.7 JTU), as was the case near the bottom (38.2 and 10.5 JTU respectively). Marsh ponds were also significantly more turbid near the surface (15.8 JTU) than were terrestrial ponds (6.8 JTU), but also at the bottom with a mean of 28.3 JTU within marsh ponds and 11.4 JTU within terrestrial ponds.

Conductance was found to be significantly greater within lacustrine ponds than within glacial till ponds throughout the water column and during both seasons. During the early season, means for each respectively were 748 and 591 umhos/cm near the surface, and 780 and 601 umhos/cm near the bottom. Similarly, late season means near the surface were 716 umhos/cm within lacustrine ponds and 550 umhos/cm within glacial till ponds, while means were 775 and 568 umhos/cm for each respectively near the bottom.

Excavated, lacustrine, and terrestrial ponds were significantly greater in light penetration throughout the season than were their counterparts. This can be attributed to the fact that ponds contributing extreme values for this parameter were characteristic of all these conditions; that being excavated, lacustrine, and terrestrial.

Sediment Analysis

In general, individual cores tended not to show patterns of undirectional increasing or decreasing percentages of total Kjeldahl nitrogen, total phosphorus (TP), or organic matter (OM) (Table 12). However, GTDL-1 displayed increasing percentages of total Kjeldahl nitrogen toward the mud-water interface as did LMBW-1. LTDF-1, on the other hand, showed decreasing percentages toward the mud-water interface. An increase in total phosphorus toward the mud-water interface was evident in cores from GMDW-1 and GMDW-2, as well as in LTDF-1. A similar trend was also found concerning percent organic matter, but only within LTDF-1. Cores from marsh ponds within the glacial till region consisted mostly of peat-like sediment, whereas all other cores were comprised of clay, sand or gravel, and fine organic material; sometimes alternating. Sediment composition in cores from two of the marsh ponds, LMBW-1 and LMBW-2, was not similar to that in cores from glacial till marsh ponds, but instead was typical of the latter characteristics.

From observance of Table 12, total Kjeldahl nitrogen percentages were higher among marsh ponds, but only in those within the glacial till region. LMBW-1 and LMBW-2 were considerably lower; the latter yet lower than the former. Percentages were the lowest in cores from LTDF-1. Percent organic matter was considerably greater in cores within marsh ponds as was total Kjeldahl nitrogen, but again, lower within LMBW-1 and LMBW-2. In addition, it was interesting to find a layer of clay at the mud-water interface from a core from LMBW-2, but which was not present in LMBW-1. Differences in percent total phosphorus between cores were tenuous, but ranged from highest levels found in cores from GTDL-1 to lowest in LTDW-1.

Associations between percentage of the above parameters and sediment composition were observed. In general, organic percentages and total Kjeldahl nitrogen percentages decreased as sediments along the core became clay-like, or were increasingly more coarse (sand/gravel). A similar trend was evident in regard to total phosphorus, except in cores from LMBW-1 and LMBW-2, in which clay-like segments showed increased amounts of phosphorus.

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Table 12. Percentages of sediment chemistry parameters within cores.

Site	Distance from Mud-water Interface (cm)	% Total Kjeldahl Nitrogen	% Total Phosphorus	% Organic Matter
GTDL-1	0-2	0.48	0.10	11.91
	9-11	0.39	0.11	13.07
	15-17	0.01	0.09	9.11
	18-20	0.01	0.10	11.37
	24-26	--	0.03	6.94
GMDW-1	0-2	1.72	0.10	53.47
	9-11	1.23	0.08	--
	40-42	1.75	0.08	--
	62-64	1.94	0.06	45.08
	80-82	1.78	0.06	45.75
GMDW-2	0-2	1.34	0.09	41.43
	19-21	1.44	0.07	33.46
	43-45	.198	0.07	47.44
	65-67	1.51	0.07	38.04
GMBW-3	0.2	1.54	0.08	37.05
	10-12	0.98	0.06	30.12
	30-32	1.75	0.10	41.09
	55-57	1.66	0.06	40.13
GMBW-4	0-2	1.45	0.07	36.10
	20-22	1.41	0.05	32.41
	40-42	1.48	0.06	33.21
LMBW-1	0-2	0.54	0.08	15.07
	7-9	0.34	0.05	15.43
	16-18	0.01	0.09	2.88
LMBW-2	0-2	0.05	0.06	8.70
	10-12	0.13	0.06	13.69
	23-25	0.01	0.06	4.72
	38-40	0.12	0.04	11.17
	48-50	0.01	0.07	3.09
LTDF-1	0-2	0.01	0.08	10.48
	15-17	0.01	0.08	7.70
	24-26	0.03	0.07	3.60
LTDL-1	0-2	0.24	0.06	7.14
	15-17	0.26	0.07	8.86
	30-32	0.01	0.04	1.39
	43-45	0.04	0.05	1.94
LTDL-2	0-2	0.17	0.07	5.12
	9-11	0.15	0.07	4.94
	17-19	0.07	0.04	2.05
	28-30	0.18	0.07	5.23
	35-37	0.04	0.04	1.71
LTDW-1	0-2	0.05	0.04	1.83
	12-14	0.23	0.05	3.06
	18-20	0.05	0.05	1.52

Linear Correlations. As with water analysis, correlation coefficients were calculated for (1) all ponds together; (2) categories of ponds; (3) individual ponds. Figure 6 gives a summary of significant correlations.

A number of studies have reported strong significant correlations between levels of nitrogen and organic matter within the sediments of lakes and wetlands (Frink 1969; Keeney et al., 1970; Larson-Albers, 1982), since most of the nitrogen in the sediments is organic. In this study, a similar correlation was observed. A coefficient of .9726 ($P < .01$) was computed from data representing all cores together, and all individual ponds, except GTDL-1, GMDW-1, and LTDF-1, displayed very strong positive associations ($P < .05$). Negative correlations were evident among GMDW-1 ($r = .7594$) and LTDF-1 ($r = -.9158$), but were not statistically significant at the 0.05 level. This relationship was found to be strong ($r > .9$) and significant ($P < .01$) within all categories except lacustrine ponds ($r = .6635$, $P < .01$) and terrestrial ponds ($r = .5325$, $P < .05$), in which correlations were weaker.

Percent total phosphorus was highly correlated with percent organic matter among cores from certain sites. GTDL-1 ($r = .9149$) and GMDW-1 ($r = .9974$) were significant at the 0.05 level, but LTDF-1 also showed a strong correlation ($r = .9158$), but was not statistically significant at this level. Two other ponds displaying strong associations were both LTDL-1 ($r = .9553$, $P < .05$) and LTDL-2 ($r = .9960$, $P < .01$). The only category of ponds to show a strong correlation between total phosphorus and organic matter was the terrestrial ponds, which had a coefficient of .8089 ($P < .01$).

T-tests. T-tests were run to determine if significant differences were evident between categories of ponds concerning percent total Kjeldahl nitrogen, percent total phosphorus, and percent organic matter at the mud-water interface only. Results are found in Table 13.

Table 13. T-test results concerning sediment chemistry at the mud-water interface between pond categories ($P = .05$). Upper case letters indicate which of the categories being compared had significantly greater means.

Categories	% TKN	% TP	% OM
Excavated (D) vs Dynamited (B)			
Glacial till (G) vs Lacustrine (L)	G		G
Marsh (M) vs Terrestrial (T)	M		M

	TKN	TP
OM	ALL + EXCAVATED + DYNAMITED + GLACIAL TILL + LACUSTRINE + MARSH + terrestrial + GMBW-3 + gmbw-4 + LMBW-2 + LTDL-1 + LTDL-2 + ltdw-1 +	TERRESTRIAL + gtdl-1 + gmdw-1 + ltdl-1 + LTDL-2 +
TP	glacial till - LTDF-1 - LTDL-2 +	

Figure 6. Summary of individual and categories of ponds which had significant correlations regarding sediment chemistry. Upper case letters = P<.01, lower case letters = P<.05, (+) = positive correlation, (-) = negative correlation.

Significant differences were absent among comparisons between excavated and dynamited ponds in regard to all three parameters. Phosphorus percentages were not found to be significantly different among any of the comparisons. With respect to total Kjeldahl nitrogen, surface samples from cores within glacial till ponds had a significantly greater mean percentage (1.31%) than did samples from lacustrine ponds (0.18%), and marsh ponds were significantly greater with a mean of 1.11 percent versus 0.19 percent within terrestrial ponds.

Results were similar concerning percent organic matter. Glacial till ponds had a significantly greater mean (35.99%) over lacustrine ponds (8.06%), and marsh ponds again being significantly greater (31.97%) than terrestrial ponds (7.30%).

Standard deviations for data within categories were considerably greater for both glacial till and marsh ponds as compared to their counterparts. One of the glacial till ponds, GTDL-1, had a lower percentage of total Kjeldahl nitrogen and organic matter at the mud-water interface than the other ponds within this category; and two of the marsh ponds, LMBW-1 and LMBW-2, also displayed much lower percentages than the other marsh ponds.

Sediment-water Relationships

Data from both sediment and water analyses were utilized in studying the relationships between the chemistry of the sediment at the mud-water interface and that within the overlying water. Linear correlation coefficients were computed separately for both surface and bottom portions of the water column during each season. Goals for this analysis were twofold: (1) to determine if any correlations were significant only during a particular season or at a particular stratum; (2) to determine if significant correlations existed within a certain category and not within its counterpart.

In the preceding section on sediment analysis, a strong and significant relationship was found between organic matter and percent total Kjeldahl nitrogen in many of the cases analyzed. The importance of this association was observed when analyzing the relationship between the sediment at the mud-water interface and the overlying water since both percent total Kjeldahl nitrogen and percent organic matter were both similarily correlated with the same parameter within the overlying water a majority of the time.

Coefficients were computed in regard to all cores in conglomerate with their respective above water chemistry. Figure 7 lists those which were found to be significant. Total phosphorus within the sediment at the mud-water interface was found to be negatively correlated with conducitivity of both surface ($r=-.7694$, $P < .01$) and bottom ($r=-.7389$, $P < .01$) samples during the early season, but correlations were not significant during the late season. Percent total Kjeldahl nitrogen and organic matter were each negatively associated with light penetration (-.6865 and -.6715 respectively, $P < .05$) during the early season, but again, not during the late season. During the late

SEDIMENT		WATER: TKN early season	TKN late season	DO early season	DO late season	COND early season	COND late season	LIGHT early season	LIGHT late season
TP	S					--			
	B				-	--			
TKN	S		+					-	
	B								
OM	S		+					-	
	B								

Figure 7. Significant correlations found using data representing all cores. Two symbols represents significance at the 0.01 level and one symbol represents significance at the 0.05 level. (+) = positive correlation, (-) = negative correlation, S = surface, B = bottom.

season, total Kjeldahl nitrogen concentrations within the surface waters were positively correlated with both sediment total Kjeldahl nitrogen and organic matter (.6741 and .6981 respectively, $P < .05$).

Discrepancies in the direction of correlations were found to be most prevalent between excavated and dynamited ponds (Table 14). Total Kjeldahl nitrogen within the overlying water near the surface was highly and significantly correlated with both percent total Kjeldahl nitrogen and organic matter at the mud-water interface during both seasons, as were total orthophosphate concentrations. Excavated ponds showed positive correlations with regard to these associations. A signifacant relationship between total Kjeldahl nitrogen within the water and with that within the sediment did not exist among dynamited ponds except during the early season near the bottom, but was instead negatively correlated. A correlatin between percent organic matter and total Kjeldahl nitrogen within the water was never significant within the dynamited ponds.

Total orthophosphate concentrations were found to be positively related to both total Kjeldahl nitrogen and organic matter within the sediment ($P < .05$) during both seasons within excavated ponds, but only near the surface. Within the dynamited ponds, these correlations were negative and were significant near the surface and the bottom during the early season, and near the surface only during the late season ($P < .05$).

Significant relationships existed concerning concentrations of dissolved oxygen with sediment total Kjeldahl nitrogen and organic matter. Among excavated ponds, negative correlations were present near the surface during the late season ($P < .01$), whereas within dynamited ponds, positive correlations existed during both seasons and near the surface only ($P < .05$). Coefficients were also negative and positive within each category respectively near the bottom during the late season, at both strata within excavated ponds during the early season, and near the bottom during the early season among the dynamited ponds, but were not significant.

Total Kjeldahl nitrogen concentrations within the water were strongly correlated with percent phosphorus within the sediment among both excavated and dynamited ponds. This was true only during the late season, and only at the water surface. This relationship, however, was found to be positive within the excavated ponds ($P < .05$), but negative among the dynamited ponds ($P < .05$). Correlations were also positive within the excavated ponds throughout the water column during the early season, and near the bottom during the late season within the dynamited ponds, but were not significant.

Light penetration was correlated with total Kjeldahl nitrogen within the sediment among both categories. A significant negative relationship was evident within excavated ponds, ($P < .01$), but only during the early season, whereas in the dynamited ponds, this association was found only during the late season, and its correlation was significantly positive ($P < .01$).

Other correlations were significant within one of the above categories, but not within the other (Table 14). A significant negative correlation bet-

Table 14. Directions of significant correlations found within excavated and dynamited ponds concerning water-sediment parameters ($P<.05$). (+) = significant correlation, (-) = significant negative correlation.

Category	Season	Depth	TKN /TKN water/sed.	TKN /OM water/sed.	PO_4-P/TKN water/sed.	PO_4-P/OM water/sed.	DO /TKN water/sed.	DO /OM water/sed.
Excavated	early	surface	+	+	+	+		
		bottom						
	late	surface	+	+	+	+	-	-
		bottom						
Dynamited	early	surface			-	-	+	+
		bottom	-		-	-		
	late	surface			-	-	+	+
		bottom						

Category	Season	Depth	TKN /TP water/sed.	Light /TKN pent./sed.	Cond /TP water/sed.	Cond /TKN water/sed.	Cond /OM water/sed.
Excavated	early	surface		-	-		
		bottom			-		
	late	surface	+				
		bottom					
Dynamited	early	surface					
		bottom					
	late	surface	-	+		-	-
		bottom				-	-

ween conductivity and sediment phosphorus existed near both the surface and bottom with respect to excavated ponds, but only during the early season ($P < .05$). This relationship was absent among dynamited ponds. A strong negative association was prevalent concerning conductivity with both total Kjeldahl nitrogen and organic matter within the sediment, but only in regard to dynamited ponds. These correlations ($r < -.99$, $P < .01$) were present at both the surface and bottom of the water column, and only during the late season. In addition, a positive correlation was found with respect to sediment total Kjeldahl nitrogen and light penetration ($P < .05$); again only during the late season.

Differences in direction of correlation were scarce between glacial till and lacustrine ponds, but a number of significant relationships were observed among glacial till ponds which were insignificant within the lacustrine ponds. One such dissimilarity in correlation direction was evident though, and concerned percent organic matter at the mud-water interface with turbidity (Table 15). This relationship was found to be negative and strong during the early season at both the surface($r = -.9595$, $P < .01$) and bottom ($r = -.9109$, $P < .05$) of the water column, and only near the bottom during the late season ($r = -.9632$, $P < .01$). However, lacustrine ponds displayed a positive relationship ($P < .05$) which was evident near the bottom during the late season. Similar correlations were found near the bottom during the early season, and also near the surface during the late season, but both were not significant.

Total Kjeldahl nitrogen within the sediment was significantly correlated with turbidity within glacial till ponds. This association was negative, and was present near the surface and near the bottom during the early season ($P < .05$), and near the bottom during the late season ($P < .05$). Such a relationship was not significant within lacustrine ponds, although they were positive except near the surface during the early season.

Likewise, percent phosphorus within the sediment was correlated with dissolved oxygen, and again, only within the glacial till ponds. During the early season, a significant negative correlation was evident near the surface and near the bottom ($P < .05$). Although never significant, negative correlations did show up in lacustrine ponds also, except near the surface during the early season when this relationship was positively correlated.

Sediment organic matter was also found to be significantly correlated within the glacial till ponds, whereas not significant within the lacustrine ponds. A positive relationship existed during the late season only, with both surface and bottom portions of the overlying water displaying significant correlations ($P < .05$). Lacustrine ponds, although not significant, did show positive correlations during the late season, and negative during the early season.

Many significant relationships among marsh ponds were found, but few of these were significant within the terrestrial ponds (Table 16). Total Kjeldahl nitrogen within the water column was significantly and negatively correlated with both phosphorus and organic matter within the sediment, but during the early season only ($P < .05$). These correlations were representative

Table 15. Directions of significant correlations found within glacial till and lacustrine ponds concerning water-sediment parameters ($P<.05$). (+) = significant positive correlation, (-) = significant negative correlation.

Category	Season	Depth	Turb /OM water/sed.	Turb /TKN water/sed.	DO /TP water/sed.	Cond /OM water/sed.
Glacial till	early	surface	-	-	-	
		bottom	-	-	-	
	late	surface				+
		bottom	-	-		+
Lacustrine	early	surface				
		bottom				
	late	surface				
		bottom	+			

Table 16. Directions of significant correlations found within marsh and terrestrial ponds concerning water-sediment parameters ($P<.05$). (+) = significant positive correlation, (-) = significant negative correlation.

Category	Season	Depth	TKN /TP water/sed.	TKN /OM water/sed.	Turb /TKN water/sed.	Turb /OM water/sed,	TKN /TKN water/sed.
Marsh	early	surface	-	-			
		bottom	-	-	-	-	-
	late	surface			-	-	
		bottom					
Terrestrial	early	surface					+
		bottom					
	late	surface					
		bottom					

of both surface and bottom water samples. Within the terrestrial ponds, these relationships were not significant. A significant negative correlation also existed concerning both total Kjeldahl nitrogen and organic matter within the sediment with turbidity, and again were not significant within the terrestrial ponds. Such correlations were prevalent near the bottom during the early season, and near the surface during the late season ($P < .05$).

Only a single significant correlation was found among the terrestrial ponds, and of which its direction was opposite that found within the marsh ponds. Total Kjeldahl nitrogen at the mud-water interface was positively correlated with total Kjeldahl nitrogen concentrations near the surface, and only during the late season ($P < .05$). These parameters were negatively related within the marsh ponds ($P < .01$); occurring only during the early season near the bottom.

Discussion

This discussion attempts to bring together the results concerning the analyses of both water and sediment physio-chemical characteristics and their relationships with each other, in hope of formulating any explanations or speculations toward interpreting the dissimilarities in water quality between ponds or groups of ponds. Much of the analysis has been statistically indicative of significant differences between the categories of ponds compared. Direction of significant correlations, the presence of strong relationships among individual ponds within specific categories, and significant differences between means all have given heed to the fact that differences between corresponding categories do exist. However, closer inspection of the statistics reveals that disparities in water quality may not have necessarily been directly dependent upon whether the ponds were excavated or dynamited, glacial till or lacustrine, marsh or terrestrial.

Dissolved Oxygen

Oxidative processes are responsible for the depletion of oxygen near the mud-water interface in water bodies, and the intensity of its exhaustion is reflected by the amount of organic matter within the superficial sediment (Wetzel, 1975). The lower levels of dissolved oxygen near the bottom were found in most of the ponds, except in those which were terrestrial and built within two years prior to sampling. The percent organic matter at the mud-water interface was also the lowest in these ponds (LTDL-1, LTDL-2, LTDW-1).

The presence of *Lemna* was important in oxygen depletion, especially when coverage was extensive for a period of time. Quade et al. (1982), in studying the ecology within a dolomite quarry, found that an algal mat covering the surface was in part responsible for the depletion of oxygen within the pit, although it only covered seventy-five percent of the surface area. Although the percent organic matter within the superficial sediment of LMBW-2 was low as compared to the other ponds (8.7%), *Lemna* coverage was extensive throughout much of the season; an impediment to both wind and light.

Marsh ponds, which had a significantly greater percentage of organic matter within the sediment, also revealed significantly lower concentrations of dissolved oxygen during the late season, and near the bottom during the early season than terrestrial ponds. All ponds that were dynamited also displayed significantly lower oxygen levels than did excavated ponds during the late season, but were not significantly different than their counterparts with regard to percent organic matter. This can be attributed to the fact that all dynamited ponds were also marsh ponds, whereas excavated ponds were both terrestrial and marsh. Lacustrine ponds, which were significantly less in dissolved oxygen than glacial till ponds, were also significantly greater in percent organic matter within the sediment.

Whether or not ponds became anoxic played an important part in the difference in correlation direction between categories concerning dissolved oxygen. It would seem likely, from the above discussion, that ponds with greater percentages of organic matter at the mud-water interface, would tend to have lower levels of dissolved oxygen, especially near the bottom. This was the case with respect to excavated ponds, but not within ponds that were dynamited; and in addition, significant correlations were only evident near the surface. Dynamited ponds with the lowest percentage of organic matter were also covered with intense blooms of Lemna (LMBW-1 and LMBW-2), whereas those with greater percentages of organic matter were not covered with Lemna at any time during the season. With regard to excavated ponds, those with greater organic matter percentages were anoxic due to Lemna cover (GMDW-1 and GMDW-2), but those with less organic matter within the sediment were not covered. In addition, LMBW-1, which had the lowest amount of organic matter, also had a large bed of Chara around its perimeter. Identical results and explanations are pertinent to the similar trends involving dissolved oxygen with percent total Kjeldahl nitrogen.

Much of the same reasoning applied to percent phosphorus within the sediment with dissolved oxygen within glacial till ponds. Among the glacial till ponds, those with greater phosphorus percentages were covered by Lemna (GMDW-1 and GMDW-2), therefore decreasing any wind fetch, and resulting in anoxic conditions; whereas GMBW-3 and GMBW-4, which had less phosphorus, were exposed to wind and were not covered by Lemna. Although GTDL-1 had the greatest percentage of phosphorus of all the glacial till ponds, Lemna did cover at times, resulting in lower oxygen concentrations, but not as significant as was observed within GMDW-1 and GMDW-2. Correlations within lacustrine ponds were never significant, were also negative, but were much weaker than those found among the glacial till ponds. This was due to the fact that those which became anoxic (LMBW-1 and LMBW-2), together did not have the greatest percentage of phosphorus.

The presence of Lemna may also have been responsible for the positive correlation found in marsh ponds between oxygen levels and depth. The depletion of oxygen accompanied the decrease in water levels as the season progressed. GTDL-1 was the only terrestrial pond in which Lemna was found, and LTDW-1 showed greater concentrations of dissolved oxygen when water levels were lower.

Total Kjeldahl Nitrogen

The depletion of oxygen near the sediment-water interface was prominent in many of the observed trends concerning total Kjeldahl nitrogen. During decomposition, heterotrophic bacteria are responsible for the generation of ammonium as an end product of this process, and in addition, the loss of an oxidized microzone at the mud-water interface when anoxic conditions persist, results in the release of ammonium from the sediment (Wetzel, 1975). Therefore, total Kjeldahl nitrogen concentrations increased in ponds with depleting levels of oxygen, and especially in those which became anaerobic. One would speculate that the reason for the absence of a strong correlation in support of this, would be that the abundance of plankton subject to decomposition varied within the ponds, and that once the mud-water interface became anoxic, total Kjeldahl nitrogen levels may have continued to rise throughout the season.

Marsh ponds, which were significantly lower in dissolved oxygen than terrestrial ponds, were also significantly greater in total Kjeldahl nitrogen levels throughout the water column during both seasons. Likewise, dynamited ponds were significantly greater in total Kjeldahl nitrogen than excavated ponds during both seasons. This seems reasonable since all dynamited ponds were marsh ponds. In light of this fact, since marsh ponds were also significantly greater than terrestrial ponds in percent organic matter and total Kjeldahl nitrogen within the superficial sediment, one might then suspect that dynamited ponds would also have been significantly greater than excavated ponds with respect to these two percentages; but such was not the case. When considering only marsh ponds, those with greater percentages of organic matter had lower concentrations of total Kjeldahl nitrogen within the water, but only during the early season when bottom waters were not anoxic (until the fourth sampling date within LMBW-1 and LMBW-2). This was most typical within GMDW-1 and GMDW-2 which were excavated ponds. In addition, these two ponds together had the highest percentages of organic matter and total Kjeldahl nitrogen within the sediment of all ponds. All other marsh ponds, which had only slightly lower concentrations of organic matter and total Kjeldahl nitrogen, were dynamited. These two reasons then explain why organic matter and total Kjeldahl nitrogen percentages were not significantly different between excavated and dynamited ponds. Therefore, the amount of organic matter and total Kjeldahl nitrogen within the superficial sediment does not seem to be solely responsible for the concentrations of total Kjeldahl nitrogen within the overlying water.

Glacial till ponds were also significantly greater in total Kjeldahl nitrogen within the water than lacustrine ponds during the late season. Three of the five glacial till ponds did become anoxic due to Lemna blooms during the late season, and therefore could have been accountable for the significant difference.

Marsh, dynamited, and glacial till ponds showed greater total Kjeldahl nitrogen concentrations when water levels decreased. Ponds characteristic of these categories were all similar in depth; all approximately one meter at the start of the sampling period. The only exception was GTDL-1. Marsh ponds were prominent in this trend with a correlation of -.6820. Water levels did decline as the season progressed, and were accompanied by the gradual increase in total Kjeldahl nitrogen as a result in oxygen depletion. Negative trends were also evident within the latter two categories, since four of the glacial till and all dynamited ponds were characteristically marsh. Terrestrial, excavated, and lacustrine ponds did not necessarily decrease in oxygen nor increase in total Kjeldahl nitrogen as water levels dropped.

Correlations concerning sediment total phosphorus with total Kjeldahl nitrogen within the overlying water are at this time difficult to resolve, since significance occured both near the surface and during the early season only. In addition, why correlations between total Kjeldahl nitrogen and total orthophosphate were greater among excavated, lacustrine, and terrestrial ponds than within their counterparts, along with relationships between total Kjeldahl nitrogen with both nitrate nitrogen and turbidity, are not easily explicable since the design of this study does not necessarily accomodate the data needed to answer these associations.

Nitrate Nitrogen

Tile lines draining agriicultural fields had a definite impact on nitrate nitrogen concentrations in those ponds in which they emptied (LTDF-1 and LTDL-1). Taylor et al. (1970) and Zwerman et al. (1972) reported nitrate concentrations at tile outlets of 10-15 to as high as 50 ppm, and 3-51 ppm respectively. Numerous studies have been done reflecting the high solubility and mobility of nitrate (Campbell and Webber, 1969; Meek et al., 1969; Biggar and Corey, 1969; Holt, 1973), which was noted to be at its highest levels with heavy rainfall, especially in the spring within these two ponds. Highest concentrations were observed in the spring and early summer by Wang and Evans (1970), and were reported to be highest in drainwater during March through May by Kolenbrander (1969). Concentrations in both of the tiled ponds decreased as the season progressed, probably because the time between field application of nitrogen and measurement increased with time (Zwerman et al., 1972), and the fact that rains were not as intense during tha latter part of the season. The implications of this were evident as was seen in concentrations that were significantly greater within the lacustrine and terrestrial ponds near the surface during the early season. Nitrate levels approached zero within LTDF-1 near the bottom due to reducing conditions.

A number of patterns with respect to nitrate nitrogen found among the ponds are not explainable at this time. It is difficult to reason why nitrate levels at the earliest part of the season were higher in LMBW-1 than in LMBW-2, since the water in each should have been chemically similar due to the flooding. Concentrations were very low within LTDL-2 and LTDW-1, even though dissolved oxygen levels needed for nitrification were the highest of all ponds. Concentrations may have declined due to utilization or immobilization. Significant correlations and trends concerning nitrate nitrogen with sediment parameters were absent.

Total Orthophosphate

Phosphorus within the sediment has very little correlation with the amount of phosphorus within the overlying water (Wetzel, 1975; Olness et al., 1979). What is important is the ability of the sediment to retain and absorb this element. This is heavily dependent upon dissolved oxygen concentrations, and therefore, the oxidation-reduction status of the sediments (Patrick and Khalid, 1974). Decomposition also contributes to the phosphorus content within the water column.

Percentages of phosphorus within the sediment at the mud-water interface within the ponds were very similar to each other (std. dev. = 0.018), but concentrations within the water column were much higher within those which became anaerobic near the bottom, especially during the late season. Marsh ponds, for example, were significantly greater in orthophosphate concentrations than were terrestrial ponds, primarily because four of the six marsh ponds became anoxic. In addition, since ponds were shallow, especially during the late season, concentrations near the surface were also significant. Stratification within LTDF-1 resulted in high levels of orthophosphate within its hypolimnion in contrast to concentrations near the surface; most likely because of anoxia, coprecipitation with organic matter and various inorganics, and its role as a nutrient trap.

The phenomenon of some ponds becoming anoxic was again seen as the primary controlling factor in correlation direction involving total orthophosphate. Its positive relationships with percent total Kjeldahl nitrogen and organic matter within the sediment, as found in excavated ponds, existed as a result of those ponds with greater total Kjeldahl nitrogen and organic matter percentages becaming anoxic, therefore resulting in greater orthophosphate levels within the overlying water. On the other hand, those with the lowest percentages among the dynamited ponds were those which became anaerobic.

Although never significantly correlated with percent phosphorus within the sediment, excavated ponds which showed greater percentages of phosphorus, also had higher concentrations of orthophosphate since these particular ponds were anaerobic. Dynamited ponds which were anoxic were those which also had less phosphorus within the sediment.

The depletion of oxygen within the dynamited and four of the six marsh ponds, due to *Lemna* coverage, was responsible for correlations of orthophosphate with water levels. Oxygen levels decreased as the season progressed, resulting in increased orthophosphate concentrations within the water as water levels dropped.

Turbidity

Definite answer explaining trends involving turbidity were difficult to formulate. However, the generation of hydrogen sulfide within LMBW-1, LMBW-2, and LTDF-1 may have had some prominence since these ponds displayed the highest values. Enough weight may have been given by values within LMBW-1 and LMBW-2, so that marsh, as well as dynamited ponds, were significantly more turbid than terrestrial and excavated ponds respectively. Even the marsh ponds, which did not produce hydrogen sulfide, became increasingly more turbid throughout the season whether or not covered by Lemna.

Heavy rains did affect the turbidity within ponds with tile drainage since they did increase in turbidity prior to the last sampling date, as well as in the spring after heavy rains. Sediments have a high capacity for transporting phosphorus since phosphates are tightly bound to sediment particles. Along with the fact that inorganic phosphate concentrations in runoff are dependent upon the amount of sediment load (Keup, 1968), orthophosphate concentrations were well correlated to turbidity values in tiled ponds since heavy rains increased turbidity levels.

Conductivity

Conductance seemed to increase only within ponds which became anaerobic, although values were not significantly greater than within those which did not. LMBW-1 and LMBW-2 showed highest levels when hydrogen sulfide was present, and gave much weight in finding significantly greater conductance within lacustrine ponds versus glacial till ponds. These two ponds were also responsible for the negative relationship found among dynamited ponds with total Kjeldahl nitrogen and organic matter within the superficial sediment. LMBW-1 and LMBW-2 showed the lowest percentages of these two parameters along with the greatest conductivity due to the hydrogen sulfide. GMBW-3 and GMBW-4 showed just the opposite.

Correlations between the dissolved oxygen content and conductivity were weak among individual ponds, but the difference in direction in significant correlations between marsh and terrestrial ponds was evident, and the lack of oxygen was in part responsible. Ponds with lower oxygen levels tended to show higher specific conductance if they were located within a marsh. This would seem reasonable since LMBW-1 and LMBW-2 were anoxic for the longest period of all the ponds, and the accompanied presence of hydrogen sulfide resulted in very high levels of ionized salts. On the other hand, ponds which were terrestrial, such as LTDL-2 and LTDW-1, which had high levels of dissolved oxygen, were also high in specific conductance. GTDL-1 was lowest in regard to both dissolved oxygen and conductivity among the terrestrial ponds.

Light Penetration

Light penetration was diminished as turbidity levels increased during the late season, although correlations did not reflect this. Weak correlations were due to the blooms of Lemna, of which were responsible for Secchi disk readings of 0.0 meters. Because of this latter fact, trends involving light penetration were meaningless.

Differences in Water Quality Between Anaerobic and Aerobic Ponds

It was evident that dissolved oxygen levels were responsible for much of the resulting chemical characteristics and patterns seen among the ponds. Whether or not a pond became anoxic, primarily due to extensive blooms of Lemna, leads one to hypothesize that this may be the determining factor in the quality of water within a shallow pond. In light of this, additional T-tests were computed to investigate if water quality was significantly different between ponds which became anoxic and those which did not. LTDF-1 was again not included. Table 17 summarizes these results.

It was most evident that water quality was significantly different between anerobic and aerobic ponds. Disolved oxygen concentrations were significantly lower throughout the water column during the entire season within ponds which did become anoxic. This was accompanied by significantly greater levels of total Kjeldahl nitrogen and total orthophosphate among these same sites. Turbidity results were similar except near the surface during the early season when means were not significantly different. Conductivity was significantly different during the late season; probably because levels within LMBW-1 and LMBW-2 were dramatically higher during this time. Light penetration was also found to be significantly less within anaerobic ponds during the entire season; primarily due to Lemna.

Figures 8, 9, 10, 11, and 12 show seasonal patterns with respect to dissolved oxygen, total Kjeldahl nitrogen, and total orthophosphate concentrations, of which the latter two increased when oxygen levels dropped toward 0.00 ppm. The dates when Lemna populations were first observed are also indicated, which seemed to correlate well with and govern dissolved oxygen concentrations.

This phenomenon was further investigated by running T-tests between four similar ponds which included two which became anaerobic and two which did not. The only difference between the two groups was that two were located within the glacial till region (GMBW-3 and GMBW-4) and the other two within the lacustrine region (LMBW-1 and LMBW-2). This was felt to be insignificant since these ponds were built within sediment well above the original calcareous till and lacustrine sediment laid down when the last glacial influence retreated. The other discrepency, which was the one of interest, was that LMBW-1 and LMBW-2 became anoxic, while GMBW-3 and GMBW-4 did not. Results are given in Table 18.

In this instance, total orthophosphate was very much responsive to decreases in dissolved oxygen; that is, when oxygen was significantly lower within anaerobic ponds, total orthophosphate concentrations were significantly greater. Total Kjeldahl nitrogen, on the other hand, was significantly greater within anaerobic ponds only when anoxic conditions prevailed for a long period of time.

In the first T-test, which included all aerobic and anaerobic ponds, four of the six anaerobic ponds were marsh ponds. Where only marsh ponds were concernd, as in the latter test, total Kjeldahl nitrogen concentrations were not

Table 17. T-test results concerning water quality parameters between ponds which became anoxic and those which did not. Letters indicate which of these groups of ponds had significantly greater means (P=.05). (N) = anaerobic, (A) = aerobic.

Season	Depth	DO	TKN	NO_3-N	PO_4-P	Turb	Cond	Light pent.
early	surface	A	N		N		A	A
	bottom	A	N		N	N	A	
late	surface	A	N		N	N		A
	bottom	A	N		N	N		

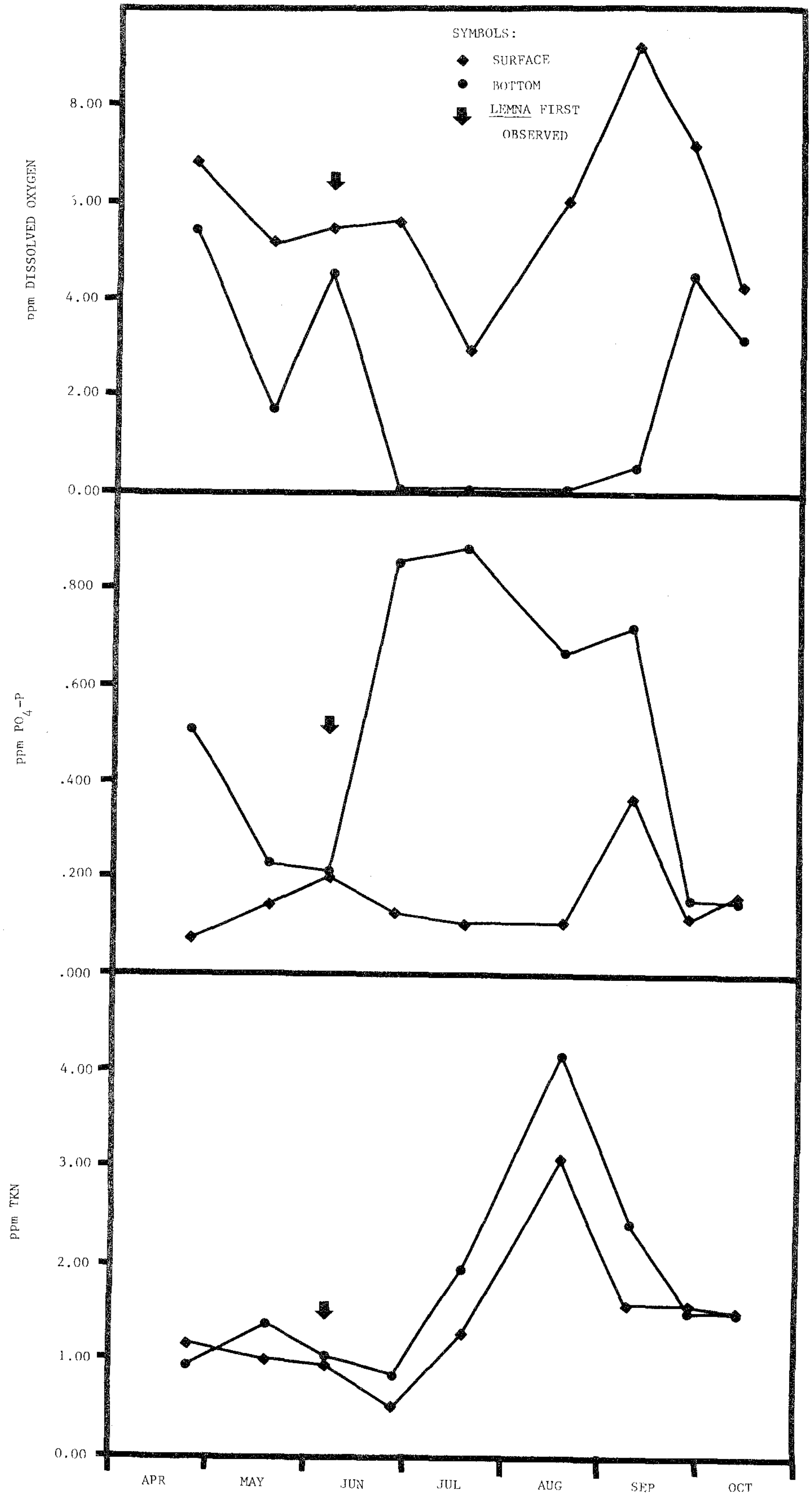

Figure 8. Changes in dissolved oxygen, total orthophosphate, and total Kjeldahl nitrogen concentrations throughout the season within GTDL-1.

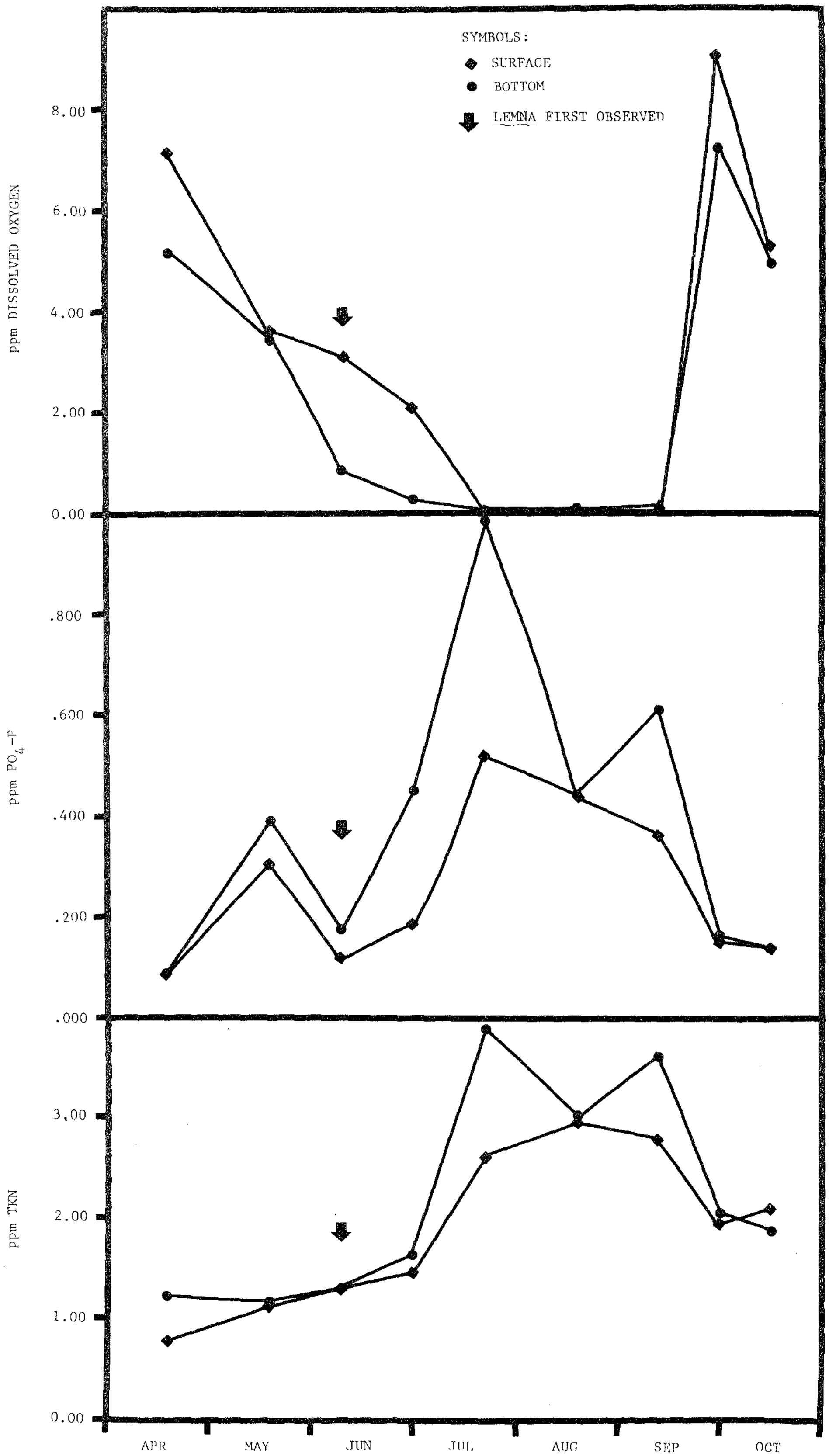

Figure 9. Changes in dissolved oxygen, total orthophosphate, and total Kjeldahl nitrogen concentrations throughout the season within GMDW-1.

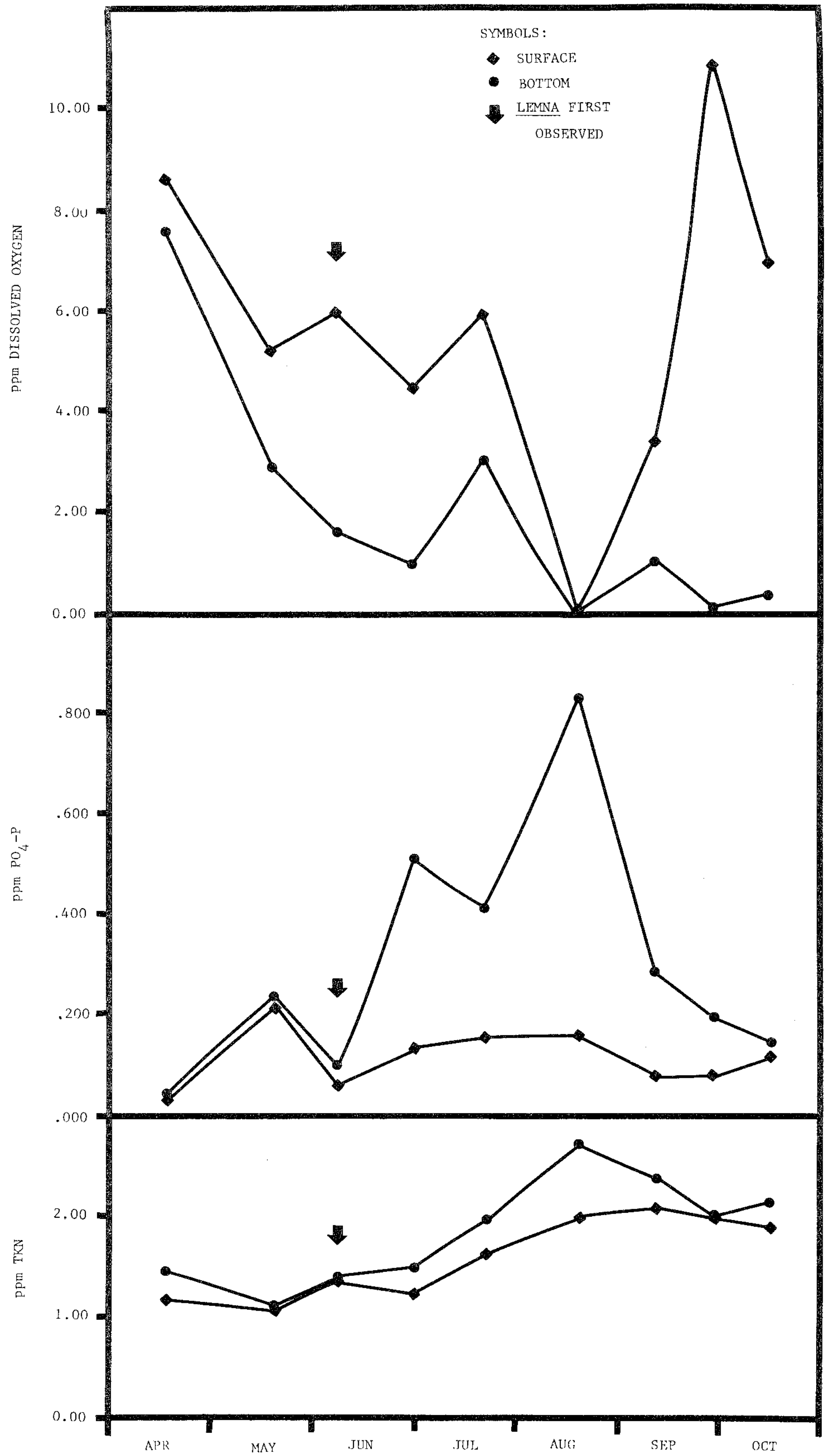

Figure 10. Changes in dissolved oxygen, total orthophosphate, and total Kjeldahl nitrogen concentrations throughout the season within GMDW-2.

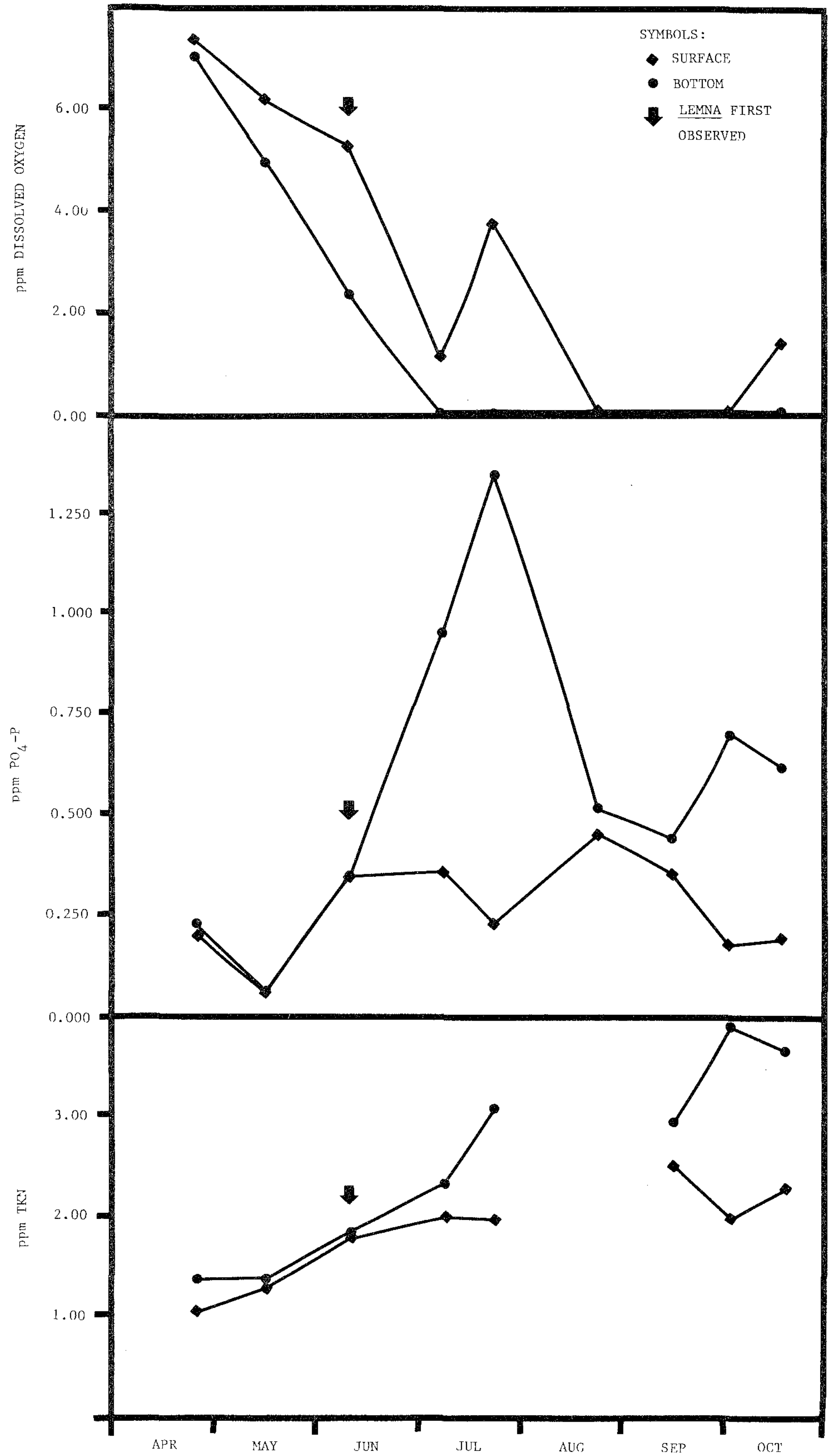

Figure 11. Changes in dissolved oxygen, total orthophosphate and total Kjeldahl nitrogen concentrations throughout the season within LMBW-1.

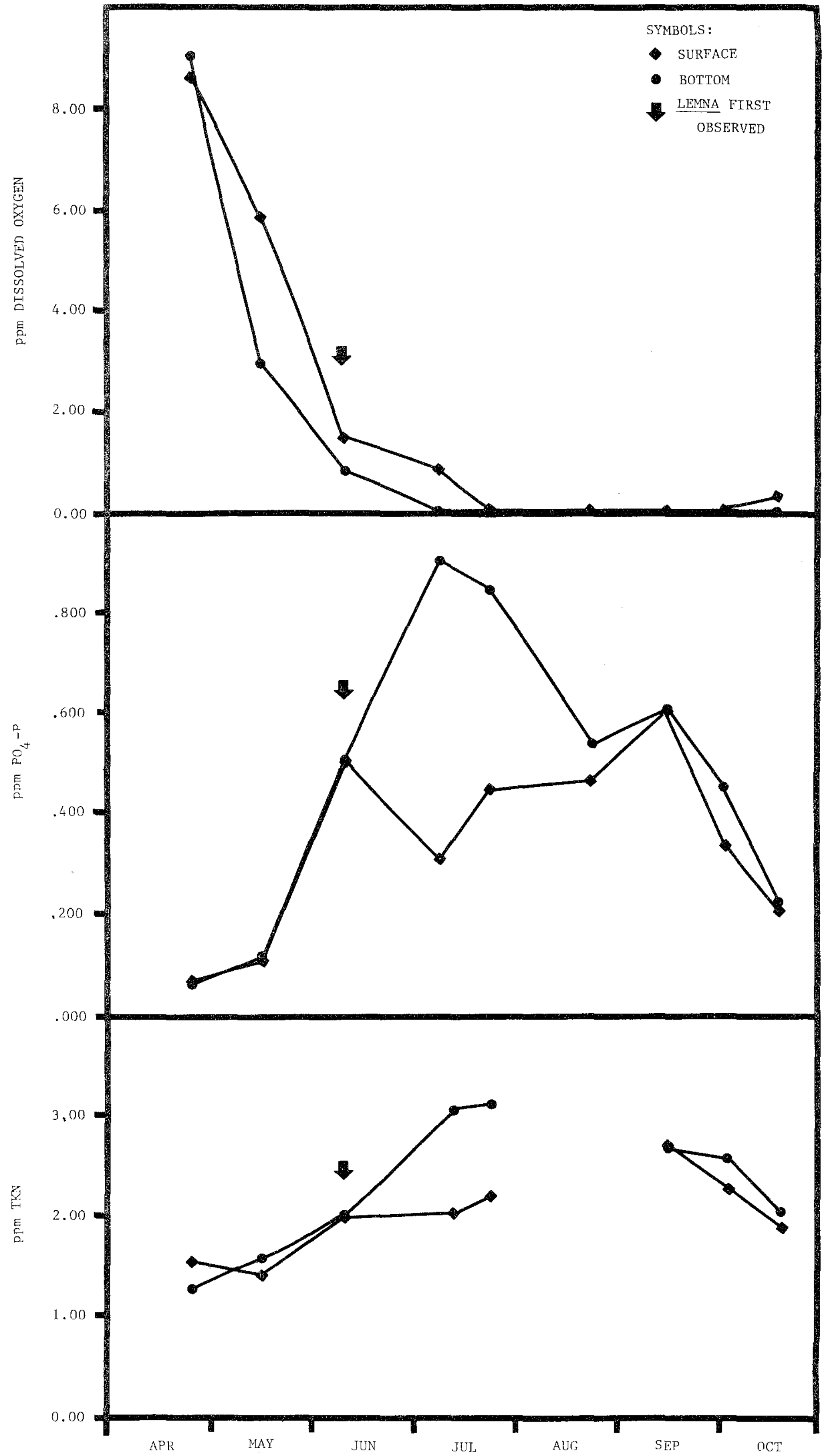

Figure 12. Changes in dissolved oxygen, total orthophosphate, and total Kjeldahl nitrogen concentrations throughout the season within LMBW-2.

Table 18. T-test results concerning water quality parameters between GMBW-3 and GMBW-4 (aerobic) and LMBW-1 and LMBW-2 (anaerobic). Letters indicate which of these groups had significantly greater means (P=.05). (N) = LMBW-1 and LMBW-2, (A) = GMBW-3 and GMBW-4.

Season	Depth	DO	TKN	NO_3-N	PO_4-P	Turb	Cond	Light pent.
early	surface	A			N			
	bottom							
late	surface	A			N		N	A
	bottom	A	N		N	N	N	

significantly different unless anoxic conditions were to persist. Unlike total Kjeldahl nitrogen, total orthophosphate levels seemed much more sensitive to dissolved oxygen concentrations when the latter approached 0.00 ppm. This gives some light to the fact that differences in water quality may be somewhat dependent upon whether or not ponds are characteristically marsh or terrestrial in setting. However, this study resulted in only one comparable case. Even so, anoxic conditions were critical to the water quality of shallow ponds, which in turn was dependent upon the status of Lemna on the surface of these ponds.

In summary, unstratified shallow ponds which do not become anoxic, but instead remain aerobic will become traps for nutrients, especially phosphorus. Phosphorus will remain trapped within the sediment as long as an oxidized microzone persists at the mud-water interface. This becomes imperative when applied to ponds with overflow pipes which may empty into other water bodies such as fluvial systems, since increased concentrations of phosphorus within the water column, due to anoxia, may be present within the outflow.

LTDF-1: An Alternative Model

LTDF-1 was the only pond which was characteristically dimictic and thermally stratified with a definite hypolimnion during the season. The hypolimnion acted as a trap for phosphorus descending from more productive water via sedimentation, coprecipitation, or from being released from the sediments.

Schreiber et al. (1980), in a study of a small detention reservoir's impact on water quality as a phosphorus trap, mention that sedimentation and flushing rate are important to a lake's tolerance to phosphorus loading. Sedimentation would occur at low flow periods, with flushing predominating during high flow periods. Since the sediment phase was the most important transport mechanism for phosphorus in their study, the trapping of phosphorus was closely related to the trapping of the sediment. The study concluded that 8-50 percent of the soluble total phosphorus and 43-79 percent of the sediment total phosphorus was trapped within the reservoir, and as a result of this, water quality at the outflow was improved. Although the experimental design in the present study did not facilitate the collection of data in order to compare actual results, pond depth, characteristics, and design were very similar.

This pond was also unique in that its outflow emptied into a riverine wetland, which in turn flowed into the Big Cobb River. Water draining through the pond's effluent pipe was epilimnetic. Although the tile line entered nearer the effluent than where open water samples of the pond were taken, the colder and thus more dense water entering the pond would have flowed beneath the epilimnion, therefore having little effect on the quality of water exiting via the outflow.

Concentrations with respect to nitrate nitrogen, total orthophosphate, turbidity, and conductivity were greater in water coming from the tile line.

This was based upon mean values calculated for the entire stratified season (excluding sampling on October 20). Mean values were found second highest within the epilimnion in regard to all above parameters except total orthophosphate, of which the wetland showed a slightly greater concentration. All remaining concentrations within the wetland were therefore the lowest among the three sites sampled, except for total Kjeldahl nitrogen which was more concentrated within the wetland. Increased total Kjeldahl nitrogen and total orthophosphate levels within the wetland were due to decomposing conditions (Lemna covered the open water areas).

In essence, this pond, as an alternative model in the design of ponds as compared to the others in this study, demonstrated a twofold function toward the betterment of water quality by acting as a nutrient trap: first, in improving its own water quality, and second, in acting as a net diluter of water from the tile input with respect to certain parameters prior to its leaving the pond.

BIOLOGICAL SURVEY

Results and Discussion

Organisms were collected from each pond only once during the season, although some unintentional observations were also made. Because of emergence, predation, or even limited sampling, some species may have been neglected, but could have been collected had sampling occurred at various times throughout the season. In light of this fact, the data below is only to be interpreted as descriptive, and not necessarily as information regarding organisms as indicator species of water quality.

Benthos

A large variety of aquatic insects and Annelida comprising the benthos in this study were found; some only in single ponds and others at a majority of sites (Table 19). The greatest number of genera were found in LTDL-1. This was the youngest pond (nearly one year), and since species diversity would be low in highly eutropic waters (Jonasson, 1969), along with the fact that fish were absent from the pond, this might very well explain the great number of genera which colonized the site. On the other hand, LTDL-2, which was very near LTDL-1 and although one year older, did contain fish, and the number of benthic genera was considerably less. A few aquatic insects including Acilius and Hygrotus (coleoptera), and Gomphidae and Libellula (odonata) were found only within LTDL-1.

The most commonly found coleoptera were Haliplus, followed by Lacophilus and Tropisternus. Members of the family Corixidae were the most common hemiptera collected, whereas water striders (Gerridae) were found at only two sites. The only hemipteran collected in ponds characteristically alike was

Table 19. Survey of benthos within each pond.

	COLEOPTERA													HEMIPTERA								ODONATA				DIPTERA		EPHEMEROPTERA	AMPHIPODA ANNELIDA	
SITE	Acilius	Agabus	Coptotmus	Dineutus	Enochrus	Haliplus	Hydaticus	Hydroporus	Hygrotus	Laccophilus	Peltodytes	Rhantus	Tropisternus	Corixidae	Belastoma	Gerris	Lethocerus	Notonecta	Plea	Ranatra	Trepobates	Gomphidae (early instar)	Anax	Enallagma	Libellula	Chironomidae	Tabanus	Callibaetis	Hyalella	Hirudinidae
GTDL-1							X			X	X	X	X	X	X			X	X					X		X			X	X
GMDW-1						X				X				X					X										X	X
GMDW-2		X	X			X							X	X					X	X								X	X	
GMDW-3			X	X		X					X		X	X			X			X			X	X			X		X	X
GMDW-4								X		X		X	X	X	X		X	X	X				X	X				X	X	X
LMBW-1										X			X		X			X		X			X	X						
LMBW-2						X				X				X	X				X					X					X	
LTDF-1					X	X														X	X			X						
LTDL-1	X			X		X		X	X	X			X	X	X			X	X			X	X	X	X					
LTDL-2						X					X				X			X					X	X					X	X
LTDW-1						X				X				X		X														

Lethocerus, which was present in both GMBW-3 and GMBW-4. In regard to odonates, the damsilfly Enallagma was prevalent within a majority of the ponds. Dipterans were rather scarce among the sites. Tabanus was collected in only one pond (GMBW-3). The only mayfly found was Callibaetis, which is known to frequent ponds, and was present only in GMDW-2 and GMBW-4. The Amphipod Hyalella was also a relatively common organism collected. Its absence within LTDF-1 and LTDW-1 may have been due to the presence of the green sunfish (Lepomis cyanella) in each of these ponds, since Hall et al. (1970) found that in experimental ponds, Lepomis preyed selectively upon the larger adult stages of Hyalella. It was somewhat surprising that chironomids were found only within GTDL-1, and absent within all other ponds.

Molluscs

Four different species of snail were collected from the ponds (Table 20), with Helisoma trivolvia and Lymnea stagnalis the most abundant. Each of these were found in all marsh ponds, but only those within the glacial till region, while the latter was limited in this study to marsh ponds only. Stagnicola emarginata was collected in only one of the ponds (GMDW-2), while a single fingernail clam (Spharidae) was found, and only within LMBW-2. Collections did not produce any snails in LMBW-1 and LTDF-1.

Zooplankton

A number of interesting observations were made concerning zooplankton collections, although not strictly with respect to actual numbers (Table 21). Some of the groups, families, or genera were present within certain groups of ponds and not within others. Calanoid copepods were not collected within any of the marsh ponds, nor within LTDL-1 or LTDL-2. However, they were found to make up a large portion of the sample within LTDF-1 with increasing percentages toward the surface. Cyclopoid members, on the other hand, tended to be greater in percentage while calanoid populations were low. The reverse was evident within those ponds mentioned above, in which calanoid copepods predominated.

The genus Chydorus was collected within LMBW-1, LMBW-2, and LTDW-1; the former two being the only marsh ponds with this genus present. LTDW-1 possessed a large bed of Chara around its perimeter, of which Quade (1969) mentions is highly associated with the presence of Chydorus. Daphnia was collected primarily within LTDF-1, LTDL-1, and LTDL-2. LTDW-1, GTDL-1, and most of the marsh ponds contained populations of Simocephalus, but most outstanding was the fact that percentages were by far the greatest within LMBW-1 and LMBW-2. Members of the family Chaoboridae were present within all ponds except GMBW-4, LTDF-1, LTDL-2, and LTDW-1. In addition, it was evident that these latter organisms were more abundant within the excavated ponds than within the dynamited ponds.

Table 20. Survey of molluscs within each pond.

SITE	*Helisoma trivolvis*	*Lymnea stagnalis*	*Physa*	*Stagnicola emarginata*	Sphaeridae (fingernail clam)
GTDL-1			X		
GMDW-1	X	X			
GMDW-2	X	X		X	
GMBW-3	X	X			
GMBW-4	X	X			
LMBW-1					
LMBW-2		X			X
LTDF-1					
LTDL-1			X		
LTDL-2	X				
LTDW-1			X		

Table 21. Percentages of the total number of zooplankton in the sample within each pond at various depths.

SITE	Calanoid	Cyclopoid	Chydorus	Daphnia	Simocephalus	Chaoboridae	Total
GTDL-1							
surface	0.5	95.0	0.0	0.2	3.0	1.3	536
1 meter	1.4	87.7	0.0	0.0	4.1	6.8	73
GMDW-1	0.0	90.9	0.0	0.0	0.6	8.5	176
GMDW-2	0.0	73.6	0.0	0.0	1.9	24.5	53
GMBW-3	0.0	83.3	0.0	0.0	4.2	12.5	24
GMBW-4	0.0	100.0	0.0	0.0	0.0	0.0	6
LMBW-1	0.0	26.9	1.6	0.0	71.4	0.1	1812
LMBW-2	0.0	46.0	26.9	0.0	26.5	0.6	513
LTDF-1							
surface	88.7	0.1	0.0	11.2	0.0	0.0	759
1 meter	80.1	1.7	0.0	18.1	0.0	0.0	629
2 meter	75.3	0.7	0.0	24.1	0.0	0.0	594
3 meter	79.5	5.4	0.0	15.2	0.0	0.0	112
4 meter	56.4	18.2	0.0	25.5	0.0	0.0	110
5 meter	58.6	6.9	0.0	34.5	0.0	0.0	29
LTDL-1							
surface	0.0	61.9	0.0	36.9	0.0	1.2	84
1 meter	0.0	35.6	0.0	61.5	0.0	2.9	104
2 meter	0.0	37.8	0.0	51.2	0.0	11.0	82
LTDL-2							
surface	0.0	41.7	0.0	58.3	0.0	0.0	12
1 meter	0.0	90.0	0.0	10.0	0.0	0.0	10
2 meter	0.0	100.0	0.0	0.0	0.0	0.0	9
LTDW-1	42.3	21.8	16.7	0.0	19.2	0.0	78

Fish

Pimephales promelas was certainly the most common fish species collected. In all ponds in which fish were collected, this species was found, except within LTDF-1. Table 22 lists the species of fish collected within each pond. LTDF-1 did have a history of stocking and had the most species including Ictalurus melas Lepomis cyanella, and Pomoxis nigromaculatus. L. cyanella was also collected within LTDW-1. This pond had been flooded by the Big Cobb River, resulting in probable isolation of fry at this site after water levels receded. It would seem dubious that fish would have survived within LMBW-1 much after the collection date since this pond became completely anoxic shortly thereafter.

Macrophytes

A number of macrophyte species were found in ponds with similar characteristics or locales (Table 23). For example, Nymphaea odorata was present only within GMBW-3 and GMBW-4, as was Potamogeton pectinatus. Likewise, LTDL-1 and LTDL-2 were the only ponds with stands of P. strictifolius and Valisneria americana. Lemna, which had a considerable impact on the dissolved oxygen levels in some of the ponds, was restricted to marsh ponds, with the exception of GTDL-1. It also tended to proliferate in ponds not affected by wind. Wolfia columbiana was also collected within marsh ponds only. Chara was the only macrophyte present within LTDW-1, but grew profusely around its perimeter. It was surprising to find evidence of Chara within GMBW-4 since it generally is associated with sand or mixtures of sand with mud or marl (Moyle, 1939) not typical of this pond. Nitella flexilla and P. nodosus were collected each within single ponds; in LMBW-1 and LTDL-2 respectively. Macrophytes were not found within LTDF-1, probably because of its extremely steep sides.

Survey results within each category, including Lemna covered ponds, are given benthos (Table 24), zooplankton, fish, and molluscs (Table 25), and for macrophytes (Table 26).

THE IMPORTANCE OF PONDS WITH RESPECT TO THEIR INTENDED PURPOSE

This thesis has focused primarily upon the importance of pond construction method and setting, and their impact on water quality, with no data development in relation to the intended purpose of these ponds. Cattle were never seen inhabiting any of the three livestock ponds; gates were closed all season long on two of them. The third one did show some evidence of its use with hoof prints at its entrance, but again, its utilization by cattle was never actually observed. Within the wildlife ponds, evidence of nesting or pairing among waterfowl species was nonexistent. Fish within LTDF-1 seemed plentiful for the few people that fished it. Because of depleted oxygen, increased hydrogen sulfide and ammonium near the bottom, the fish population was most likely restricted to the upper portion of the pond. Further, fish were present within six other ponds which were not constructed for this purpose. These observations negated statistical testing.

Table 22. Survey of fish within each pond.

SITE	*Ictalurus melas*	*Lepomis cyannela*	*Pimephales promelas*	*Pomoxis nigromaculatus*
GTDL-1				
GMDW-1				
GMDW-2			X	
GMDW-3			X	
GMBW-4			X	
LMBW-1			X	
LMBW-2				
LTDF-1	X	X		X
LTDL-1				
LTDL-2			X	
LTDW-1		X	X	

Table 23. Survey of macrophytes within each pond.

SITE	*Ceratophyllum demersum*	*Chara* sp.	*Lemna* spl	*Nitella flexilla*	*Nymphaea odorata*	*Potamogeton nodosus*	*Potamogeton pectinatus*	*Potamogeton strictifolius*	*Vallisneria americana*	*Wolfia columbiana*
GTDL-1			X							
GMDW-1			X							
GMDW-2	X		X							X
GMDW-3			X		X		X			
GMDW-4		X	X		X		X			
LMBW-1			X	X						
LMBW-2	X		X							
LTDF-1										
LTDL-1								X	X	
LTDL-2		X				X		X	X	
LTDW-1		X								

Table 24. Survey of benthos within each category.

CATEGORIES	*Acilius*	*Agabus*	*Coptotmus*	*Dineutus*	*Enochrus*	*Haliplus*	*Hyadaticus*	*Hydroporus*	*Hygrotus*	*Laccophilus*	*Peltodytes*	*Rantus*	*Tropisternus*	Corixidae	*Belastoma*	*Gerris*	*Lethocerus*	*Notonecta*	*Plea*	*Ranatra*	*Trepobates*	Gomphidae (early instar)	*Anax*	*Enallagma*	*Libellula*	Chironomidae	*Tabanus*	*Callibaetis*	*Hyalella*	Hirundinidae
Excavated	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X		X	X	X
Dynamited			X			X		X		X	X	X	X	X	X		X	X	X	X			X	X			X	X	X	X
Glacial till		X	X	X		X	X	X		X	X	X	X	X	X		X	X	X	X			X	X		X	X	X	X	X
Lacustrine	X			X	X	X		X	X	X	X		X	X	X	X		X	X	X	X	X	X	X	X				X	X
Marsh		X	X	X		X		X		X	X	X	X	X	X		X	X	X	X			X	X			X	X	X	X
Terrestrial	X			X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X			X	X
Lemna covered		X	X			X	X			X	X	X	X	X	X			X	X	X			X	X		X		X	X	X

Table 25. Survey of zooplankton, fish, and molluscs within each category.

CATEGORIES	Calanoid	Cyclopoid	*Chydorus*	*Daphnia*	*Simocephalus*	Chaoboridae	*Ictalurus melas*	*Lepomis cyanella*	*Pimephales promelas*	*Pomoxis nigromaculatus*	*Helisoma trivolvis*	*Lymnea stagnicola*	*Physa*	*Stagnicola emarginata*	Spharidae
Excavated	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Dynamited		X	X		X	X			X		X	X			X
Glacial till	X	X		X	X	X			X		X	X	X	X	
Lacustrine	X	X	X	X	X	X	X	X	X	X	X	X	X		X
Marsh		X	X		X	X			X		X	X		X	X
Terrestrial	X	X	X	X	X	X	X	X	X	X	X		X		
Lemna covered	X	X	X	X	X	X			X		X	X	X	X	X

Table 26. Survey of macrophytes within each category.

CATEGORIES	*Ceratophylum demersum*	*Chara* sp.	*Lemna* sp.	*Nitella flexilla*	*Nymphaea odorata*	*Potamogeton nodosus*	*Potamogeton pectinatus*	*Potamogeton strictifolius*	*Vallisneria americana*	*Wolfia columbiana*
Excavated	X	X	X			X		X	X	X
Dynamited	X	X	X	X	X		X			
Glacial till	X	X	X		X		X			X
Lacustrine	X	X	X	X		X		X	X	
Marsh	X	X	X	X	X		X			X
Terrestrial		X	X			X		X	X	
Lemna covered	X		X							X

CONCLUSION

This study has addressed the question on whether or not the quality of water within farm ponds in Blue Earth County is influenced by method of construction, geomorphic setting, or by hydrologic setting. The statistical methods employed indicated significant differences in water and sediment chemistry between the categories of ponds with respect to various parameters. However, method of construction and setting may not have been the prominent factor responsible for these dissimilarities, although whether ponds were characteristically marsh or terrestrial may have had some bearing on differences in water quality, simply because differences in land drainage capacities result in disparate soil characteristics.

It was hypothesized that the presence of Lemna, with its potential impact on oxygen depletion when blooms were extensive, may have been the most important element influencing the resulting water quality within the ponds. Although this hypothesis was tested, and it was determined that ponds with extreme Lemna coverage showed significantly greater total orthophosphate and total Kjeldahl nitrogen concentrations, the multitude of variables present within such a study design demands variable controlled experiments in the future.

Shaffer-Cowley (1980), in a study concerning land-use changes in the Blue Earth River Valley between the years 1938-1974, reported a forty-five percent decrease in scrub area (sparsely treed, brushy area) due to maturation toward a river bottom climax forest. Much of this was attributed to a decrease in livestock grazing along the river, resulting in increased confinement of these animals within feedlots and upland pasture. Two objectives are achieved by this practice: the first being that river bank erosion due to excessive grazing is reduced, and second, direct defication by livestock within the river is eliminated. The utilization of livestock ponds then as drinking oases therefore replaces the rivers with respect to this need; in turn, meeting the first of the above two objectives. However, ponds with overflow pipes which become anoxic remain unchecked in regard to the retainment of eutrophying nutrients within the pond, therefore defeating the second of these goals.

With respect to differences in water quality between aerobic and anaerobic ponds, two models concerning future design of ponds are proposed. Each is oriented toward retaining nutrients within the pond sediment by acting as nutrient traps, especially phosphorus. Ponds should be built deep enough to enable a hypolimnion to persist during the ice-free season. If instead a shallow pond is of need or interest, such as for livestock, the absence of high steep banks and extremely tall surrounding vegetation, prevention of Lemna populations, or by orienting the pond such that wind fetch may be maximized would aid in maintaining high oxygen levels within the ponds, whereby the effectiveness of the trap would be enhanced.

Further research in relation to this subject is suggested. One possibility would be to study the impact on water quality of harvesting or poisoning the *Lemna* within ponds which presently are covered with *Lemna*. A study testing the impact of light and wind could be undertaken utilizing non-*Lemna* covered ponds by covering them with a polyethylene sheet so as to impede both light and wind. In addition, a laboratory study involving the effect of surface sediment upon the overlying water could be attempted, in which sediments from ponds comprising the variables utilized in the present study would be subjected to aerobic and anaerobic conditions. This would allow one to investigate the degree of impact of sediment chemistry upon the chemistry within the water column as influenced by the pond's method of construction or setting.

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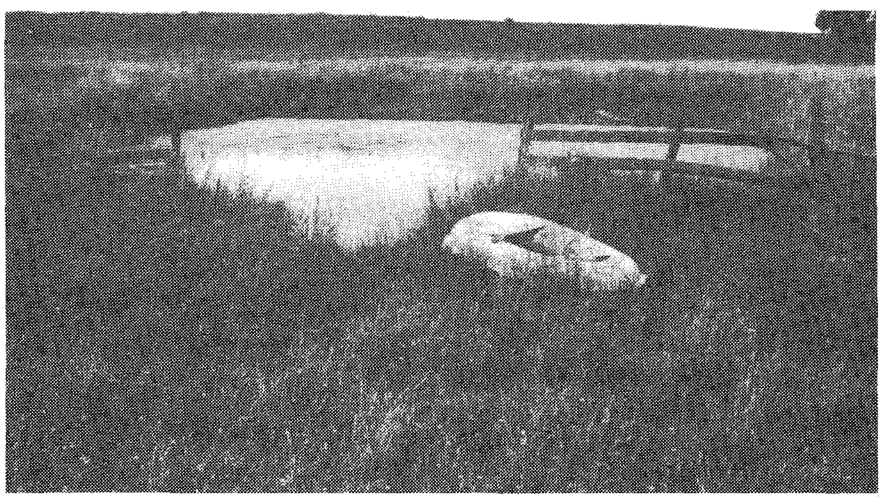
APPENDIX A

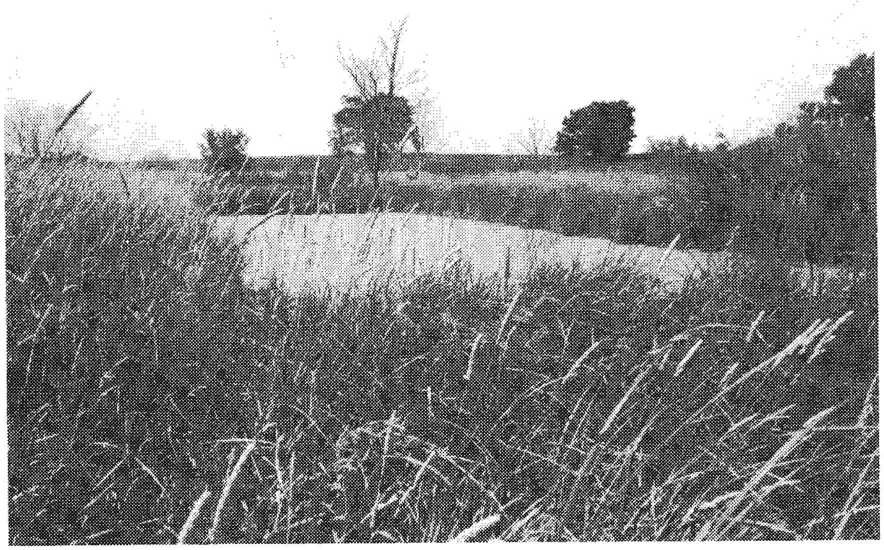
PHOTOGRAPHS OF THE SITES

GTDL-1 on May 14, 1982.



GTDL-1 on July 19, 1982.

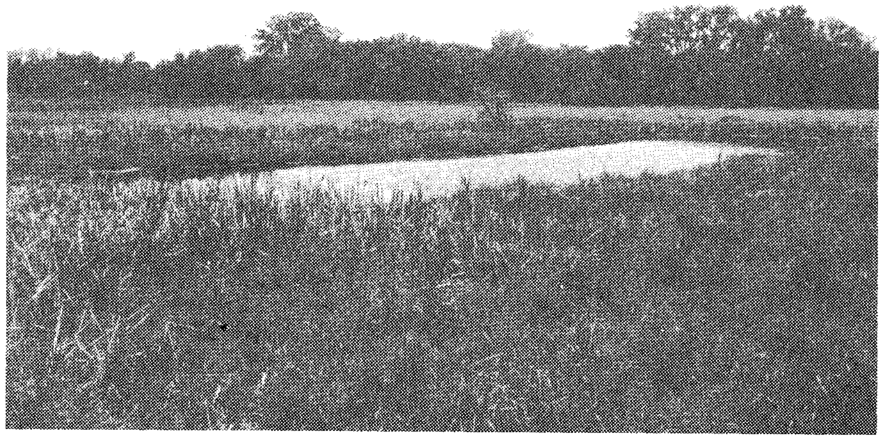
GMDW-1 on May 18, 1982.



GMDW-1 on July 20, 1982.

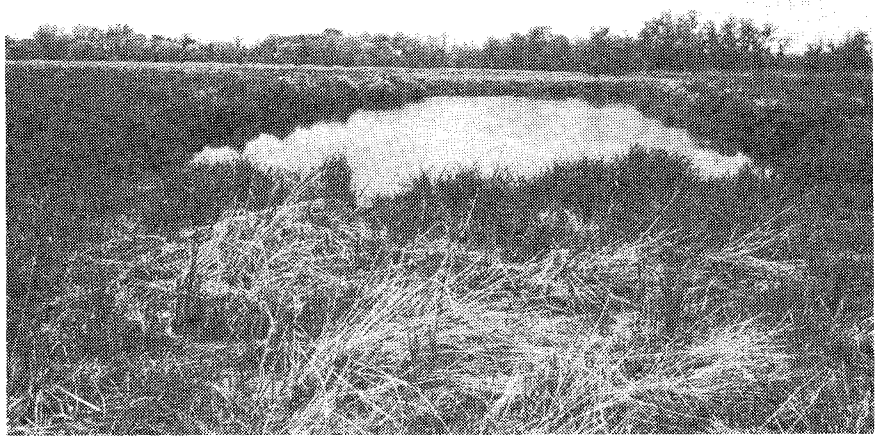
GMDW-2 on May 18, 1982.

GMDW-2 on July 20, 1982.



GMBW-3 on May 19, 1982.

GMBW-3 on July 21, 1982.



GMBW-4 on May 19, 1982.

GMBW-4 on July 21, 1982.

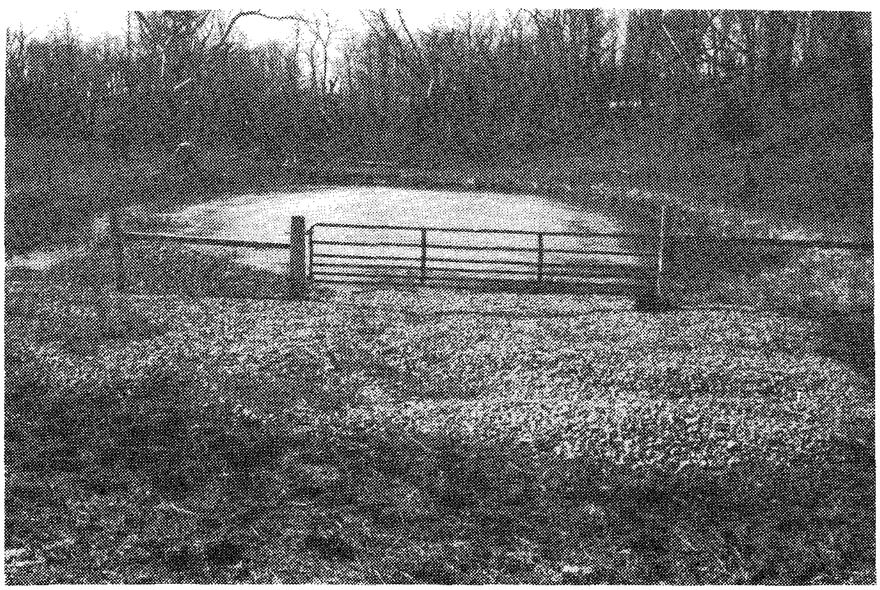
LMBW-1 on May 15, 1982.

LMBW-1 on July 22, 1982.

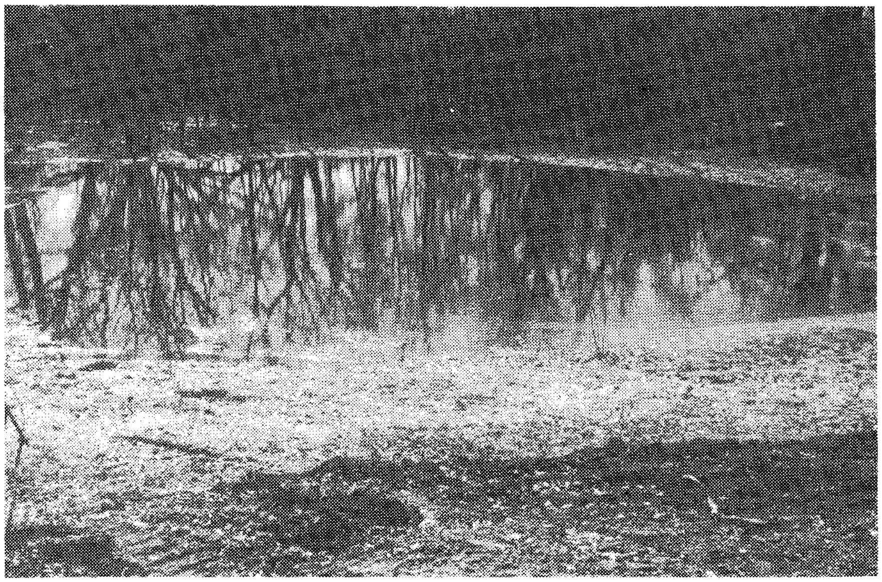
LMBW-2 on May 15, 1982.

LMBW-2 on July 22, 1982.

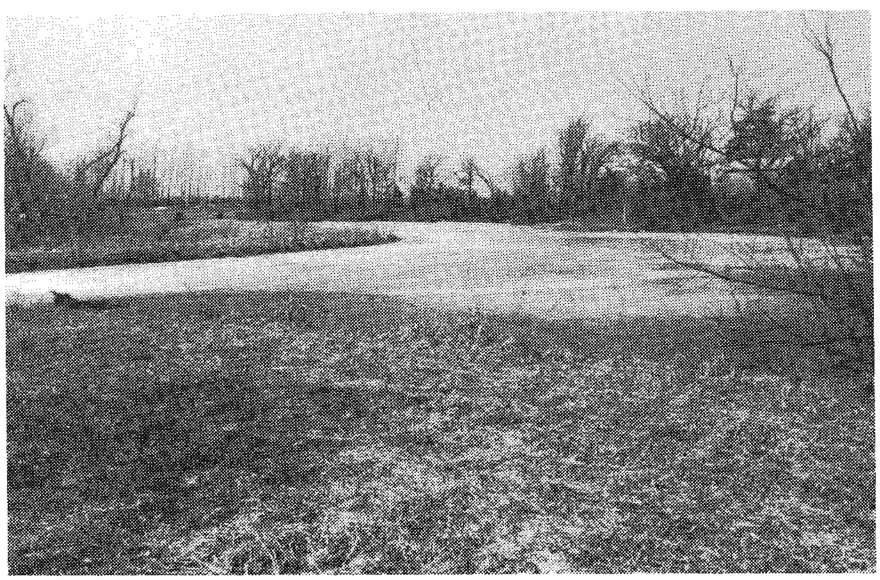
LTDL-1 on March 27, 1982.



LTDL-2 on March 27, 1982.



LTDW-1 on March 27, 1982.



LTDF-1 on March 27, 1982.

APPENDIX B

PHYSIO-CHEMICAL DATA WITHIN THE WATER COLUMN
AT EACH SITE DURING THE 1982 SAMPLING SEASON

Physio-chemical data of GTDL-1.

Date (1982)	Sample Depth (m)	Dissolved Oxygen (ppm)	Total Kjeldahl Nitrogen (ppm)	Nitrate Nitrogen (ppm)	Total Ortho-phosphate (ppm)	Turbidity (JTU)	Conductivity (umhos/cm)	Temperature (°C)	Light Penetration (m)	Depth of Pond (m)
	0.2	6.81	1.15	0.308	0.074	5.0	560	12.0		
4-23	1.0	6.85	1.01	0.111	0.135	5.5	540	10.0	0.7	1.89
	1.7	5.43	0.92	0.294	0.508	26.5	560	8.0		
	0.2	5.22	0.98	0.076	0.141	3.0	590	20.0		
5-14	1.0	4.48	1.04	0.057	0.144	2.5	550	19.0	1.6	1.96
	1.7	1.69	1.36	0.108	0.233	14.0	590	17.0		
	0.2	5.49	0.93	0.290	0.203	70.0	280	17.5		
6-7	1.0	5.10	1.01	0.300	0.214	71.5	260	15.0	0.2	1.90
	1.7	4.55	1.01	0.309	0.213	72.5	255	15.0		
	0.2	5.65	0.49	0.064	0.122	5.0	395	21.5		
6-28	1.0	0.46	0.51	0.099	0.189	8.0	395	18.0	0.0	1.85
	1.6	0.00	0.83	0.304	0.848	35.0	440	16.5		
	0.2	2.97	1.25	0.127	0.099	9.0	430	24.0		
7-19	0.8	0.00	1.43	0.256	0.340	26.5	435	22.0	0.5	1.78
	1.6	0.00	1.95	0.434	0.883	41.0	465	18.0		
	0.2	6.08	3.09	0.473	0.107	18.0	420	24.5		
8-18	0.8	1.81	3.51	0.239	0.296	26.0	455	22.5	0.4	1.52
	1.5	0.00	4.15	0.321	0.669	33.5	495	19.5		
	0.2	9.36	1.57	0.297	0.370	27.5	425	25.5		
9-10	0.8	0.56	1.54	0.228	0.406	29.0	420	19.0	0.0	1.77
	1.6	0.52	2.41	0.302	0.720	44.5	425	19.0		
	0.2	7.28	1.57	0.285	0.117	14.5	415	19.0		
9-27	0.8	4.82	1.63	0.162	0.154	14.0	400	17.0	0.5	1.77
	1.6	4.51	1.49	0.167	0.156	14.0	400	17.0		
	0.2	4.32	1.49	0.063	0.162	14.5	385	10.5		
10-13	0.8	3.71	1.54	0.063	0.151	15.5	365	10.0	0.8	1.80
	1.6	3.20	1.49	0.069	0.154	14.5	365	10.0		

Physio-chemical data of GMDW-1.

Date (1982)	Sample Depth (m)	Dissolved Oxygen (ppm)	Total Kjeldahl Nitrogen (ppm)	Nitrate Nitrogen (ppm)	Total Ortho-phosphate (ppm)	Turbidity (JTU)	Conductivity (umhos/cm)	Temperature (°C)	Light Penetration (m)	Depth of Pond (m)
4-17	0.2	7.19	0.75	0.135	0.086	1.5	420	15.0	1.2	1.30
	1.0	5.18	1.20	0.111	0.074	4.5	500	9.0		
5-18	0.2	3.64	1.10	0.188	0.305	1.5	680	25.0	0.7	1.22
	1.0	3.43	1.15	0.196	0.391	2.5	685	17.5		
6-8	0.2	3.18	1.29	0.189	0.115	2.0	575	18.5	0.0	1.22
	1.0	0.83	1.31	0.378	0.172	4.5	580	15.0		
6-30	0.2	2.19	1.45	0.186	0.184	2.5	595	20.0	0.6	1.13
	1.0	0.29	1.63	0.240	0.451	7.0	615	16.5		
7-20	0.2	0.00	2.60	0.255	0.523	3.0	685	25.0	0.0	1.09
	1.0	0.00	3.88	0.276	0.996	4.5	745	21.1		
8-19	0.2	0.00	2.93	0.298	0.441	6.5	650	21.0	0.0	0.73
	0.5	0.00	3.01	0.294	0.446	6.5	645	20.0		
9-11	0.2	0.14	2.78	0.353	0.368	5.0	870	21.5	0.4	0.89
	0.7	0.00	3.62	0.329	0.614	7.5	780	18.0		
9-29	0.2	9.16	1.94	0.293	0.156	7.0	700	20.5	0.3	0.96
	0.7	7.30	2.05	0.279	0.164	6.5	690	19.0		
10-15	0.2	5.38	2.10	0.267	0.139	5.0	620	10.0	0.0	1.10
	1.0	4.95	1.88	0.250	0.137	6.5	600	10.0		

Physio-chemical data of GMDW-2.

Date (1982)	Sample Depth (m)	Dissolved Oxygen (ppm)	Total Kjeldahl Nitrogen (ppm)	Nitrate Nitrogen (ppm)	Total Ortho-phosphate (ppm)	Turbidity (JTU)	Conductivity (umhos/cm)	Temperature (°C)	Light Penetration (m)	Depth of Pond (m)
4-17	0.2	8.30	1.15	0.325	0.025	4.0	510	16.0	0.9	1.45
	1.0	7.61	1.43	0.446	0.040	5.0	520	12.0		
5-18	0.2	5.22	1.02	0.141	0.210	2.0	765	25.0	0.7	1.39
	1.0	2.84	1.11	0.248	0.234	2.5	695	18.5		
6-8	0.2	5.97	1.32	0.899	0.061	5.0	580	19.5	0.9	1.39
	1.0	1.59	1.37	0.889	0.102	3.0	595	15.5		
6-30	0.2	4.46	1.22	0.129	0.128	3.0	515	23.0	0.6	1.30
	1.0	0.98	1.46	0.199	0.509	10.0	585	21.0		
7-20	0.2	5.92	1.64	0.170	0.152	4.0	540	28.5	0.7	1.26
	1.0	2.99	1.94	0.253	0.412	7.5	585	22.0		
8-19	0.2	0.30	1.96	0.248	0.164	7.0	545	23.0	0.5	0.99
	0.9	0.00	2.70	0.358	0.828	15.0	650	18.5		
9-11	0.2	3.42	2.11	0.293	0.079	8.0	620	22.0	0.4	1.07
	1.0	1.01	2.36	0.350	0.283	11.0	650	18.0		
9-29	0.2	10.89	1.95	0.290	0.078	10.5	595	22.0	0.3	1.13
	1.0	0.18	2.05	0.396	0.197	11.5	620	17.0		
10-15	0.2	6.99	1.89	0.317	0.115	10.0	565	10.5	0.0	1.20
	1.0	0.34	2.17	0.241	0.144	12.0	580	10.0		

Physio-chemical data of GMBW-3.

Date (1982)	Sample Depth (m)	Dissolved Oxygen (ppm)	Total Kjeldahl Nitrogen (ppm)	Nitrate Nitrogen (ppm)	Total Ortho-phosphate (ppm)	Turbidity (JTU)	Conductivity (umhos/cm)	Temperature (°C)	Light Penetration (m)	Depth of Pond (m)
4-23	0.2	7.09	1.42	0.175	0.020	7.5	670	13.0	0.5	1.40
	1.0	6.81	1.38	0.404	--	10.0	650	10.0		
5-19	0.2	7.43	1.36	0.197	0.076	4.5	735	27.0	0.5	1.33
	1.0	2.45	1.38	0.215	0.118	6.0	735	19.0		
6-8	0.2	8.28	1.13	0.138	0.052	2.5	520	21.5	0.7	1.31
	1.0	7.52	1.10	0.138	0.057	3.5	495	18.0		
7-1	0.2	6.81	1.32	0.141	0.022	6.0	595	22.0	0.5	1.23
	1.0	5.58	1.31	0.143	0.019	6.0	585	22.0		
7-21	0.2	4.53	1.61	0.219	0.029	9.5	550	28.0	0.4	1.19
	1.0	3.66	1.70	0.152	0.034	10.0	555	27.0		
8-20	0.2	4.39	2.09	0.212	0.044	15.5	470	24.0	0.3	0.98
	0.9	3.58	2.28	0.210	0.033	17.0	485	24.0		
9-11	0.2	6.76	2.04	0.293	0.040	18.5	490	24.5	0.3	1.05
	1.0	5.17	2.13	0.266	0.045	18.0	495	18.0		
10-1	0.2	6.58	2.46	0.276	0.049	19.5	425	--	0.3	1.10
	1.0	4.59	2.26	0.279	0.045	20.0	420	--		
10-16	0.2	8.47	2.07	0.233	0.046	17.0	455	12.5	0.3	1.13
	1.0	6.12	2.47	0.214	0.051	18.0	440	9.0		

Physio-chemical data of GMBW-4.

Date (1982)	Sample Depth (m)	Dissolved Oxygen (ppm)	Total Kjeldahl Nitrogen (ppm)	Nitrate Nitrogen (ppm)	Total Ortho-phosphate (ppm)	Turbidity (JTU)	Conductivity (umhos/cm)	Temperature (°C)	Light Penetration (m)	Depth of Pond (m)
4-23	0.2	7.68	1.80	0.555	0.022	7.0	800	14.0	0.4	1.21
	1.0	7.53	1.94	0.413	0.042	7.5	880	13.0		
5-19	0.2	8.35	1.37	0.246	0.033	5.0	780	25.5	0.5	1.19
	1.0	6.74	1.33	0.175	0.046	5.0	785	19.0		
6-8	0.2	9.71	1.42	0.217	0.117	2.5	605	22.0	0.7	1.21
	1.0	4.93	1.42	0.219	0.125	3.0	605	18.5		
7-1	0.2	7.52	1.61	0.209	0.121	9.0	650	22.5	0.4	1.14
	1.0	1.23	1.66	0.237	0.251	10.0	665	21.5		
7-21	0.2	4.09	2.05	0.453	0.049	6.5	605	28.0	0.4	1.11
	1.0	2.36	2.15	0.242	0.056	5.5	640	27.0		
8-20	0.2	4.34	2.39	0.287	0.058	14.5	515	24.5	0.3	0.85
	0.8	3.70	2.53	0.296	0.057	12.5	525	24.0		
9-11	0.2	9.14	2.20	0.299	0.025	7.5	550	24.5	0.5	0.98
	0.9	3.40	2.54	0.506	0.029	12.5	575	21.5		
10-1	0.2	8.40	2.22	0.480	0.031	13.0	500	--	0.4	1.05
	1.0	6.25	2.40	0.379	0.031	13.0	505	--		
10-16	0.2	10.38	2.21	0.238	0.039	8.5	560	13.5	0.4	1.09
	1.0	10.84	2.44	0.243	0.040	10.0	550	8.5		

Physio-chemical data of LMBW-1.

Date (1982)	Sample Depth (m)	Dissolved Oxygen (ppm)	Total Kjeldahl Nitrogen (ppm)	Nitrate Nitrogen (ppm)	Total Ortho-phosphate (ppm)	Turbidity (JTU)	Conductivity (umhos/cm)	Temperature (°C)	Light Penetration (m)	Depth of Pond (m)
4-24	0.2	7.44	1.08	1.176	0.199	7.0	650	11.5	0.6	--
	1.0	7.13	1.32	1.220	0.202	7.5	640	11.0		
5-15	0.2	6.21	1.26	0.242	0.044	2.0	630	19.0	1.0	1.60
	1.0	4.95	1.31	0.091	0.054	2.5	675	17.5		
6-10	0.2	5.26	1.76	0.117	0.330	6.5	690	19.5	1.1	1.29
	1.0	2.35	1.82	0.387	0.334	6.5	675	17.0		
7-6	0.2	1.13	1.95	0.125	0.347	2.0	700	23.0	0.9	1.18
	1.0	0.00	2.31	0.172	0.953	69.0	1130	19.0		
7-22	0.2	3.76	1.92	0.170	0.227	2.0	780	24.0	0.8	1.27
	1.0	0.00	3.07	0.202	1.350	99.9	1025	19.0		
8-23	0.2	0.00	--	0.348	0.440	47.0	795	19.0	0.0	0.73
	0.5	0.00	--	0.327	0.520	61.0	780	18.5		
9-14	0.2	0.00	2.49	0.241	0.342	69.0	740	16.0	0.0	0.99
	0.9	0.00	2.90	0.258	0.437	90.0	750	17.0		
10-2	0.2	0.00	1.93	0.365	0.176	8.0	750	--	0.0	0.98
	0.7	0.00	3.88	0.448	0.694	82.0	880	--		
10-18	0.2	1.35	2.27	0.199	0.186	3.0	890	10.0	0.8	1.04
	1.0	0.00	3.64	0.263	0.624	89.0	915	9.0		

Physio-chemical data of LMBW-2.

Date (1982)	Sample Depth (m)	Dissolved Oxygen (ppm)	Total Kjeldahl Nitrogen (ppm)	Nitrate Nitrogen (ppm)	Total Ortho-phosphate (ppm)	Turbidity (JTU)	Conductivity (umhos/cm)	Temperature (°C)	Light Penetration (m)	Depth of Pond (m)
4-24	0.2	8.64	1.52	0.158	0.066	14.0	625	15.0	0.4	--
	1.0	9.07	1.25	0.154	0.062	10.0	635	13.5		
5-15	0.2	5.86	1.37	0.102	0.106	2.0	650	19.5	1.0	1.04
	1.0	2.94	1.57	0.111	0.118	3.5	685	18.0		
6-10	0.2	1.43	1.95	0.138	0.501	5.5	720	20.0	0.9	0.94
	0.9	0.80	1.97	0.138	0.507	6.0	710	18.0		
7-6	0.2	0.82	2.01	0.208	0.305	7.5	815	22.0	0.0	0.98
	0.9	0.00	3.09	0.255	0.899	48.5	925	16.0		
7-22	0.2	0.00	2.18	0.318	0.447	6.5	960	23.5	0.0	1.02
	1.0	0.00	3.10	0.343	0.840	58.0	1210	18.0		
8-23	0.2	0.00	--	0.298	0.457	27.0	885	19.0	0.0	0.64
	0.5	0.00	--	0.319	0.533	28.0	905	18.5		
9-14	0.2	0.00	2.68	0.318	0.602	47.0	825	17.0	0.0	0.93
	0.9	0.00	2.64	0.290	0.604	47.5	830	17.5		
10-2	0.2	0.00	2.26	0.314	0.336	18.0	800	--	0.0	0.93
	0.7	0.00	2.59	0.323	0.447	36.5	855	--		
10-18	0.2	0.30	1.86	0.201	0.204	9.5	915	10.0	0.5	0.98
	0.9	0.00	2.04	0.201	0.221	10.5	900	8.0		

Physio-chemical data of LTDF-1.

Date (1982)	Depth (m)	Dissolved Oxygen (ppm)	Total Kjeldahl Nitrogen (ppm)	Nitrate Nitrogen (ppm)	Total Ortho-phosphate (ppm)	Turbidity (JTU)	Conductivity (umhos/cm)	Temperature (°C)	Light Penetration (m)	Depth of Pond (m)
	0.2	7.53	0.97	0.849	0.031	7.5	385	--		
	2.5	4.48	0.87	4.520	0.010	2.0	580	--		
4-27	5.0	1.07	2.01	1.701	0.158	5.0	645	--	0.9	5.26
	T	--	0.92	1.120	0.011	3.5	380	--		
	W	--	1.01	0.042	0.020	4.0	395	--		
	0.2	7.68	1.01	7.668	0.096	2.0	570	18.0		
	2.5	3.26	1.51	5.331	0.163	2.0	615	11.5		
5-16	5.0	0.55	2.70	0.212	0.492	7.5	605	8.0	2.1	5.24
	T	--	0.77	11.802	0.088	2.5	765	--		
	W	--	0.97	0.539	0.169	1.0	455	--		
	0.2	8.59	0.81	6.765	0.102	3.5	530	21.0		
	2.5	4.64	1.13	6.988	0.177	4.0	550	15.0		
6-14	5.0	0.00	3.92	0.288	1.210	31.0	590	9.5	1.5	5.22
	T	--	0.77	9.914	0.079	2.5	645	--		
	W	--	1.04	0.091	0.109	2.0	465	--		
	0.2	8.96	1.00	4.468	0.011	2.5	550	25.0		
	2.5	5.00	1.63	10.893	0.131	5.0	635	19.5		
7-7	5.0	0.00	5.86	0.096	1.827	62.0	650	10.0	1.6	5.25
	T	--	0.96	9.066	0.034	2.0	1010	--		
	W	--	1.22	0.052	0.090	2.0	440	--		
	0.2	12.83	0.37	3.320	0.010	2.5	505	28.0		
	2.5	5.06	0.63	2.803	0.022	7.0	585	22.5		
7-29	5.0	0.00	5.65	0.042	1.966	65.0	700	10.5	1.0	5.20
	T	--	0.40	3.578	0.023	4.5	565	--		
	W	--	0.67	0.082	0.068	4.5	440	--		
	0.2	7.00	--	0.662	0.066	2.5	465	--		
	2.5	1.19	--	0.414	0.130	7.5	490	--		
8-24	5.0	0.00	--	0.163	2.718	69.5	675	--	1.1	5.06
	T	--	--	0.890	0.058	3.0	450	--		
	W	--	--	0.103	0.028	4.0	405	--		

Physio-chemical data of LTDF-1 (continued).

Date (1982)	Sample Depth (m)	Dissvlved Oxygen (ppm)	Total Kjeldahl Nitrogen (ppm)	Nitrate Nitrogen (ppm)	Total Ortho-phosphate (ppm)	Turbidity (JTU)	Conductivity (umhos/cm)	Temperature (°C)	Light Penetration (m)	Depth of Pond (m)
	0.2	6.00	1.16	0.060	0.024	3.5	410	20.0		
	2.5	5.81	1.45	0.048	0.031	3.5	400	20.0		
9-15	5.0	0.00	13.82	0.132	3.509	68.0	665	11.0	1.3	5.11
	T	--	1.23	2.979	0.150	12.0	600	--		
	W	--	1.46	0.127	0.073	6.0	410	--		
	0.2	7.27	1.12	0.116	0.051	5.0	425	--		
	2.5	7.33	1.36	0.122	0.055	5.5	450	--		
10-3	5.0	0.00	12.84	0.374	3.562	72.0	680	--	0.9	5.10
	T	--	1.21	0.736	0.223	20.0	800	--		
	W	--	1.43	0.113	0.044	5.0	435	--		
	0.2	6.97	1.86	0.571	0.250	20.0	390	10.0		
	2.5	6.94	1.87	0.547	0.251	21.5	385	10.5		
10-20	5.0	7.23	1.80	0.950	0.308	39.5	380	10.0	0.3	5.30
	T	--	1.81	7.173	0.729	69.0	265	--		
	W	--	1.43	0.092	0.060	3.5	360	--		

Physio-chemical data of LTDL-1.

Date (1982)	Sample Depth (m)	Dissolved Oxygen (ppm)	Total Kjeldahl Nitrogen (ppm)	Nitrate Nitrogen (ppm)	Total Ortho-phosphate (ppm)	Turbidity (JTU)	Conductivity (umhos/cm)	Temperature (°C)	Light Penetration (m)	Depth of Pond (m)
4-30	0.2	11.45	0.21	16.663	0.005	2.0	700	--	2.5	2.56
	1.0	9.07	0.60	17.316	0.004	1.0	695	--		
	2.0	8.83	0.67	17.784	0.005	1.0	690	--		
5-21	0.2	8.37	0.71	27.710	0.075	1.5	7.5	11.0	2.5	2.59
	1.0	9.61	0.76	28.016	0.079	2.5	700	11.0		
	2.0	8.03	0.68	25.485	0.085	8.0	695	11.0		
6-15	0.2	11.41	0.75	26.549	0.014	3.5	795	18.0	0.8	2.55
	1.0	12.03	0.72	27.375	0.017	3.5	795	16.0		
	2.0	11.24	--	27.158	0.016	3.0	790	15.0		
7-8	0.2	6.72	1.19	26.146	0.056	2.5	800	20.0	1.8	2.55
	1.0	6.67	1.22	19.408	0.067	2.5	800	19.0		
	2.0	5.71	1.31	19.448	0.085	3.5	800	19.0		
7-30	0.2	9.96	0.43	15.346	0.032	2.0	765	25.5	2.1	2.52
	1.0	10.04	0.43	19.004	0.012	2.0	795	25.0		
	2.0	10.27	0.37	17.136	0.273	2.5	835	25.0		
8-25	0.2	8.67	--	10.050	0.011	3.5	525	23.0	1.0	2.34
	1.0	8.35	--	18.707	0.012	3.5	505	23.0		
	2.0	9.78	--	11.697	0.017	4.0	505	23.0		
9-22	0.2	10.66	1.19	8.229	0.075	2.5	470	20.0	1.2	2.41
	1.0	11.03	1.54	7.549	0.045	6.5	530	18.5		
	2.0	11.32	1.33	7.301	0.049	2.5	425	18.0		
10-4	0.2	8.19	1.70	5.225	0.015	4.5	410	--	0.9	2.37
	1.0	8.53	1.95	5.557	0.019	5.0	480	--		
	2.0	8.03	1.69	5.415	0.017	3.5	400	--		
10-21	0.2	10.11	1.35	16.125	1.050	36.0	495	11.0	0.3	2.57
	1.0	8.77	1.63	10.285	1.079	37.5	470	8.5		
	2.0	8.34	1.72	10.454	1.184	40.5	455	8.0		

Physio-chemical data of LTDL-2.

Date (1982)	Sample Depth (m)	Dissolved Oxygen (ppm)	Total Kjeldahl Nitrogen (ppm)	Nitrate Nitrogen (ppm)	Total Ortho-phosphate (ppm)	Turbidity (JTU)	Conductivity (umhos/cm)	Temperature (°C)	Light Penetration (m)	Depth of Pond (m)
	0.2	5.25	0.73	0.186	0.011	2.5	880	--		
4-30	1.0	5.67	0.67	0.037	0.008	3.0	910	--	1.1	2.55
	2.0	6.69	0.52	0.038	0.008	2.5	900	--		
	0.2	4.70	0.67	0.050	0.005	2.5	795	12.0		
5-21	1.0	6.94	0.68	0.004	0.003	2.5	795	12.0	1.4	2.57
	2.0	8.11	0.71	0.044	0.007	2.0	795	12.0		
	0.2	8.66	0.67	0.078	0.008	1.0	855	23.5		
6-15	1.0	8.61	0.72	0.015	0.005	1.0	855	22.0	2.4	2.55
	2.0	8.17	0.66	0.015	0.008	1.0	870	21.5		
	0.2	7.91	0.93	0.016	0.011	2.0	850	26.5		
7-8	1.0	8.04	0.96	0.008	0.009	2.0	850	26.0	1.6	2.53
	2.0	7.69	0.97	0.010	0.004	2.0	880	25.0		
	0.2	9.66	0.21	0.034	0.011	1.5	800	28.5		
7-30	1.0	9.13	0.22	0.018	0.007	1.5	800	28.0	2.2	2.47
	2.0	9.00	0.23	0.026	0.008	1.5	930	26.0		
	0.2	5.28	--	0.023	0.010	2.0	795	24.0		
8-25	1.0	5.23	--	0.019	0.005	2.0	795	24.0	1.6	2.35
	2.0	3.65	--	0.021	0.012	2.0	800	24.0		
	0.2	8.31	1.05	0.040	0.011	2.5	795	20.0		
9-22	1.0	8.17	1.04	0.037	0.044	3.0	765	17.0	1.0	2.48
	2.0	7.57	1.01	0.043	0.003	3.0	765	16.0		
	0.2	8.49	1.15	0.036	0.009	2.0	870	--		
10-4	1.0	8.46	1.15	0.040	0.010	3.0	990	--	1.1	2.48
	2.0	7.65	1.03	0.036	0.010	3.0	870	--		
	0.2	8.92	1.09	0.021	0.016	3.5	800	10.5		
10-21	1.0	8.28	1.23	0.023	0.008	4.0	795	9.0	0.9	2.59
	2.0	8.06	1.27	0.032	0.012	4.0	800	8.5		

Physio-chemical data of LTDW-1.

Date (1982)	Sample Depth (m)	Dissolved Oxygen (ppm)	Total Kjeldahl Nitrogen (ppm)	Nitrate Nitrogen (ppm)	Total Ortho-phosphate (ppm)	Turbidity (JTU)	Conductivity (umhos/cm)	Temperature (°C)	Light Penetration (m)	Depth of Pond (m)
4-30	0.2	4.99	0.72	0.056	0.010	1.0	870	--	1.7	1.74
	1.5	4.01	0.64	0.038	0.021	1.0	845	--		
5-21	0.2	4.87	0.84	0.046	0.099	1.5	740	11.5	1.7	1.72
	1.5	4.14	0.88	0.044	0.096	2.0	750	9.5		
6-15	0.2	6.87	0.70	0.037	0.076	1.0	815	23.0	1.7	1.70
	1.5	5.64	0.71	0.035	0.068	2.5	820	18.0		
7-8	0.2	6.60	1.08	0.026	0.014	2.0	655	25.0	1.1	1.12
	1.0	4.35	1.11	0.032	0.034	11.5	690	22.0		
7-30	0.2	7.07	0.29	0.024	0.061	6.5	625	25.0	0.6	0.92
	0.9	6.16	0.11	0.034	0.034	11.0	620	23.5		
8-25	0.2	6.16	--	0.025	0.031	10.0	585	20.0	0.5	0.67
	0.5	5.07	--	0.030	0.022	10.0	580	20.0		
9-22	0.2	13.34	1.07	0.037	0.002	2.0	545	16.5	0.8	0.80
	0.6	14.47	0.98	0.056	0.003	4.0	515	14.5		
10-4	0.2	9.29	--	0.045	0.011	1.0	595	--	0.7	0.80
	0.5	11.97	0.98	0.050	0.009	2.0	625	--		
10-25	0.2	15.16	0.48	0.025	0.015	2.0	500	12.5	1.0	1.02
	1.0	13.27	0.40	0.021	0.021	2.5	585	11.5		